IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

A Design and Implementation of Handwritten Digit Recognition Based on DBN

Zefeng Li[1, a], Han Ma[2,b,*]

[1,2]School of Data Science, City University of Macau, Macau, China

[a]tkllndxn@163.com (Zefeng Li), [b]D18091105035@cityu.mo

Abstract: The principle of deep belief network is to combine the low-level feature combination with the higher-level feature combination, and the unsupervised learning method reduces the amount of personnel labor. The main method of using DBN for handwritten digit recognition is studied. Using the pictures in the data for training, the accuracy is as high as 93.42%. Higher than the SVM under the same conditions. In addition, the introduction of the Dropout parameter in the deep learning network can achieve higher recognition accuracy with a small number of samples.

Keywords: DBN ; learning rate ; handwritten digit recognition.

1. INTRODUCTION

1.1 The Concept of Handwritten Number Recognition

Handwritten digit recognition is a type of traditional machine computer learning. His primary purpose was to identify the Arabic numerals given by giving the computer a large amount of handwritten Arabic numerals and testing the handwritten Arabic numerals. The process of handwritten digit recognition is easy to operate and has other characteristics such as simplicity [1]. At the same time, contemporary handwritten digit recognition has a large number of prospects and utilization needs, and the space for presentation can be very large, such as greatly speeding up the rate of handwritten digit recognition, enhancing the accuracy, or finding more precise research methods.

1.2 The Concept of Handwritten Digit Recognition

In this highly developed era, handwritten digit recognition uses various aspects, such as public security, finance, and express delivery. The use of handwritten digit recognition in various professional technical fields can greatly improve the efficiency of various industries and even work [2]. Of course, handwritten digit recognition is the basis for other recognitions. For example, fingerprint recognition is more accurate recognition based on digital recognition.

(1)The simplicity of Arabic numerals. The simplicity of the layout results in fewer features of each number. It is generally beneficial to enhance the computer, but the difficulty lies in the key to handwriting: if the characteristics of these simple features are indistinguishable and the algorithm is difficult to identify, then The possibility of algorithm error recognition is greatly increased.

(2) Speed and accuracy. In most industries, people's requirements for accuracy, accuracy, and speed are gradually increasing. For example, in the express delivery industry, accurate identification of

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

numbers is one of the foundations for accelerating express delivery. Of course, the increase in recognition speed can also greatly reduce the time of work. However, the algorithm has a limited capacity margin, and the algorithm processes more data, which will affect the rate of the algorithm.

(3) Different ways of writing. The way numbers are written is very different. The way of writing in different countries and even in the field is different. This requires handwritten digit recognition to enter a higher category. Such as Figure 1.1 .

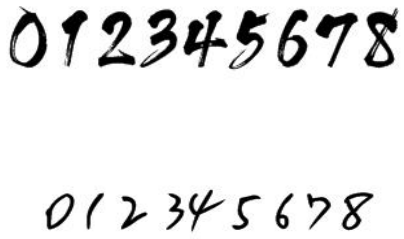

Figure 1.1 . Examples of Handwritten Numbers.

1.3 The Concept of Machine Learning

Machine learning is also a concept with multiple definitions, but at its core, machine learning is a system that can modify its behavior autonomously according to its own experience, with little human interference. This behavior modification basically involves establishing logic rules to improve the performance of the task or to make the most appropriate decision based on the application [3]. These rules are generated based on pattern recognition in the analysis data.

For example, if a person types the word "brave" in a search engine, the service needs to analyze a series of parameters to determine whether to display results that are similar to irritating or brave, which may have two meanings. There is a user search history among the many available parameters: for example, if you are looking for a few minutes before "Brave", then the second meaning is most likely to occur. This is a very simple example, but it illustrates some important aspects

If there is a need, use italic for emphasizing a word or phrase. Use boldface typing only for section headings and subheadings. of machine learning.

Importantly, the system must analyze based on large amounts of data, a criterion that searchers must abandon because they receive millions of visits, so this is a training standard.

Another aspect is continuous data entry that facilitates the identification of new standards. Suppose the word "brave" becomes a slang related to the cultural movement. Through machine learning, the

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

search engine will be able to identify patterns that point to the new meaning of the term, and after a while, will be able to consider it in the search results.

There are several ways to learn machine. One well-known method is called "deep learning", in which a large amount of data comes from multi-layer artificial neural networks, which are inspired by the structure of brain neurons that solve complex problems, such as object recognition in images.

1.4 The Concept of Neural Network

Artificial Neural Networks (abbreviated as ANNs), also referred to as Neural Networks (NNs) or Connection Models, is an algorithmic mathematics that mimics the behavioral characteristics of animal neural networks and performs distributed parallel information processing. model [4]. This kind of network relies on the complexity of the system to adjust the relationship between a large number of internal nodes to achieve the purpose of processing information.

Artificial Neural Network: A mathematical model for applying information processing similar to the structure of brain synaptic connections. It is also often referred to as "neural network" or neural network in engineering and academia.

Research content: The research content of neural network is quite extensive, reflecting the characteristics of multidisciplinary cross-technical fields. The main research work focuses on the following aspects: biological prototype: research on the biological prototype structure and functional mechanism of nerve cells, neural networks and nervous systems from the aspects of physiology, psychology, anatomy, brain science and pathology. Modeling: Based on the study of biological prototypes, theoretical models of neurons and neural networks are established. These include conceptual models, knowledge models, physicochemical models, mathematical models, and so on. Algorithm: Based on the theoretical model research, construct a specific neural network model to realize computer simulation or human neural network preparation hardware, including network learning algorithm research. This work is also known as technical model research. The algorithm used by neural networks is vector multiplication, and symbolic functions and their various approximations are widely used. Parallelism, fault tolerance, hardware implementation, and self-learning are some of the basic advantages of neural networks, and the difference between neural network computing methods and traditional methods. For many years, people have tried to understand and answer the above questions from the perspectives of medicine, biology, physiology, philosophy, informatics, computer science, cognitive science, and organizational synergy. In the process of searching for the answers to the above questions, an emergingmultidisciplinary cross-technology field has emerged, called the “neural network”. The research of neural networks involves many subject areas, which combine, infiltrate and promote each other. Scientists from different fields have started to ask different questions from different perspectives and from different perspectives. Artificial neural networks must first learn with certain learning criteria before they can work. Now, the artificial neural network is used to identify the two letters “A” and “B”. It is stipulated that when “A” is input into the network, “1” should be output, and when the input is “B”, the output is "0". Therefore, the criteria for e-learning should be: If the network makes a wrong decision, then learning through the network should make the network less likely to make the same

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

mistake next time. First, assign a random value in the interval of (0, 1) to each connection weight of the network, input the image mode corresponding to "A" to the network, and the network will weight the input mode, compare it with the threshold, and then perform non-transfer. Linear operation, get the output of the network. In this case, the probability that the network outputs "1" and "0" is 50% each, that is, it is completely random. At this time, if the output is "1" (the result is correct), the connection weight is increased so that the network can still make a correct judgment when it encounters the "A" mode input again.

The function of a normal computer depends on the knowledge and capabilities given in the program. Obviously, it will be very difficult for intelligent activities to be compiled through summarization.

Artificial neural networks also have initial adaptive and self-organizing capabilities. Change synaptic weight values during learning or training to suit the requirements of the surrounding environment. The same network can have different functions depending on the learning method and content. An artificial neural network is a learning system that can develop knowledge that exceeds the designer's original level of knowledge. Usually, its learning and training methods can be divided into two types, one is supervised or called a tutor, then use the given sample criteria for classification or imitation; the other is unsupervised learning or instructor learning At this time, only the learning mode or some rules are specified, and the specific learning content varies with the environment in which the system is located (ie, the input signal condition), and the system can automatically discover the environmental characteristics and regularity, and has a function similar to the human brain.

The neural network is like a child who loves to learn. You teach her her knowledge, she will not forget and will apply what she has learned. We add each input in the Learning Set to the neural network and tell the neural network what the classification should be. After all the learning sets have been run, the neural network summarizes her own ideas based on these examples. How she summed up is a black box. Then we can use the neural network to test the test examples in the Test Set separately. If the test passes (such as 80% or 90% accuracy), then the neural network is successfully built. We can then use this neural network to judge the classification of transactions.

The neural network explores the model simulating thefunction of the human brain nervous system by modeling and coupling the basic unit of the human brain, and develops an artificial intelligence processing function such as learning, association, memory and pattern recognition. system. An important feature of neural networks is that they can learn from the environment and store the results of learning in the synaptic connections of the network. The learning of neural network is a process. Under the excitation of its environment, it successively inputs some sample patterns to the network, and adjusts the weight matrix of each layer of the network according to certain rules (learning algorithm). Convergence to a certain value, the learning process ends. Then we can use the generated neural network to classify the real data.

1.5 The Concept of Deep Learning

Deep learning (DL) is a method of learning and characterization based on data in machine learning. It is a machine learning method that can simulate the neural structure of the human brain. The concept

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

of deep learning stems from the study of artificial neural networks. The Artificial Neural Network (ANN) abstracts the human brain neural network from the perspective of information processing, establishes a simple model, and forms different networks according to different connection methods, which are referred to as neural networks or neural networks. Therefore, deep learning, also known as Deep Neural Networks (DNN), was developed from the previous artificial neural network ANN model.

Deep learning is a new field in machine learning research. Its motivation lies in the establishment and simulation of the neural network for the analysis and learning of the human brain. It mimics the mechanism of the human brain to interpret data such as images, sounds and texts. Deep learning can make computers have the same wisdom, and their development prospects must be unlimited.

Like the machine learning method, the deep machine learning method also has the distinction between supervised learning and unsupervised learning. The learning models established under different learning frameworks are very different. For example, ConvoluTIonal Neural Networks (CNNs) is a machine learning model under deep supervision and learning, and DeepBelief Nets (DBNs) is a machine learning model under unsupervised learning.

The techniques involved in deep learning are: linear algebra, probability and information theory, under-fitting, over-fitting, regularization, maximum likelihood estimation and Bayesian statistics, stochastic gradient descent, supervised learning and unsupervised learning, before depth Feed network, cost function and back propagation, regularization, sparse coding and dropout, adaptive learning algorithm, convolutional neural network, cyclic neural network, recurrent neural network, deep neural network and deep stacking network, LSTM long and short memory, main Component analysis, regular autoencoder, characterization learning, Monte Carlo, constrained Bozman machine, deep confidence network, softmax regression, decision tree and clustering algorithm, KNN and SVM, generation of confrontation networks and directed generation networks, machines Visual and image recognition, natural language processing, speech recognition and machine translation, finite Markov, dynamic programming, gradient strategy algorithms, and enhanced learning (Q-learning).

To discuss deep learning, you will definitely talk about the word “Depth” and “depth” is the number of layers. The calculation involved in generating an output from an input can be represented by a flow graph: a flow graph is a graph that can represent computations, in which each node represents a basic calculation and a computational The value, the result of the calculation is applied to the value of the child node of this node. Consider a computational set that can be allowed in every node and possible graph structure, and defines a family of functions. The input node has no parent node and the output node has no child nodes. A special attribute of this flow graph is depth: the length of the longest path from one input to one output.

A neural network with a depth of more than 8 layers is called deep learning. A multi-layer learning model with multiple hidden layers is the architecture of deep learning. Deep learning can form a more abstract high-level representation attribute category or feature by combining low-level features to discover distributed feature representations of data.

IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

The "depth" of deep learning refers to the number of layers experienced from the "input layer" to the "output layer", that is, the number of layers of the "hidden layer", and the more layers, the deeper the depth. So the more complex the choice problem, the more depth levels are needed. In addition to the number of layers, the number of "neurons" - yellow small circles per layer is also large. For example, AlphaGo's policy network is 13 layers, with 192 neurons per layer.

Deep learning can learn a deep nonlinear network structure, realize complex function approximation, characterize the distributed representation of input data, and demonstrate the powerful ability to learn the essential features of data sets from a small sample set. The benefit of multiple layers is that you can represent complex functions with fewer parameters.

The essence of deep learning is to learn more useful features by constructing machine learning models with many hidden layers and massive training data, so as to ultimately improve the accuracy of classification or prediction. Therefore, the "depth model" is the means, and "feature learning" is the purpose. Deep learning emphasizes the depth of the model structure, highlights the importance of feature learning, and transforms the feature representation of the sample in the original space into a new feature space through layer-by-layer feature transformation, making classification or prediction easier. Compared with the method of constructing features by artificial rules, using big data to learn features is more capable of portraying rich intrinsic information of data.

1.6. Three Typical Models of Deep Learning

1.6.1 DBN Model

The Deep Belief Network (DBN) was proposed by Professor Hinton in 2006 [5]. The composition of the DBN is composed of the output layer and multiple RBMs (restricted Zil). The structure is shown in Figure 1.2 .

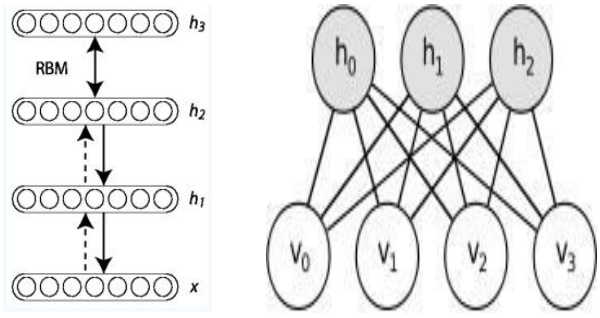

Figure 1.2 . The structure of RBM

RBM is an undirected graph model, and the composition of the RMB is divided into an abstraction layer and a hidden layer. The visible layer consists of the input layers of the data, and the different abstract layers form the hidden layer [6]. There are many nodes in each layer, and these nodes are not connected to each other. The fully connected nodes are in different layers.

IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

The DBN training process is step-by-step, pre-processing the data and then making simple adjustments to the results. Before training, an unsupervised greedy layer is used, and the gradient descent method is used to avoid local minima, such as contrast divergence (CD) and continuous reversal (PCD). That is, each layer of RBM from bottom to top is a continuous unsupervised learning. In this case, the training set becomes a training set with special identification, and the training algorithm also changes its propagation direction into a standard error algorithm [7]. Through the summary debugging of the obtained information features, a better recognition level was finally achieved.

1.6.2 CNN Model

The learning method of convolutional neural network (CNN) belongs to one layer to multiple layers, and its parameters can be trained to different degrees. After convolutional neural network training, the characteristics in the picture can be grasped, and the pictures are not summarized on this basis. , classification and extraction [8]. Experiments using the trained convolutional neural network can improve the conviction of the search and reduce the complexity of the experiment. The neural network region is gradually enlarged to form a convolutional neural network, and the upper region of the convolutional neural network is excited to form a neural network of this layer [9]. This feature makes convolutional neural networks more suitable for applications that analyze and retrieve images as shown in Figure 1.3 .

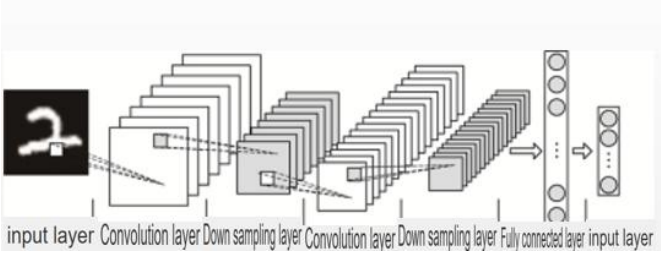

Figure 1.3 . The structure of CNN

1.6.3 SAE Model

The automatic encoder is a neural network model formed by data-driven and unsupervised data learning. Its use does not require simple marking of network model samples. The encoder portion projects the input data into the feature space, and the decoder portion projects the feature into the data space to complete the reconstruction of the input data [10]. The way to reduce the error is to determine by the minimum value, and to find out the characteristics of each data and the spatial mapping of the data.

The three-layer network in this model has the same structure and consists of an input layer and an output layer (and the number of neurons is the same). The number of intermediate layer neurons is much smaller than the other layers. The learning of neural networks helps to improve work efficiency and quality of work.

IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

2. Handwritten Digit Recognition Overall Algorithm Flow

There are not many process steps in handwritten digit recognition. The data can be trained or the handwritten numbers can be recognized. The process of training is the process of converting handwritten numbers into DBNs. The process of recognition is the process of processing the data and numbers to obtain the results. Overall as shown in Figure 2.1 .

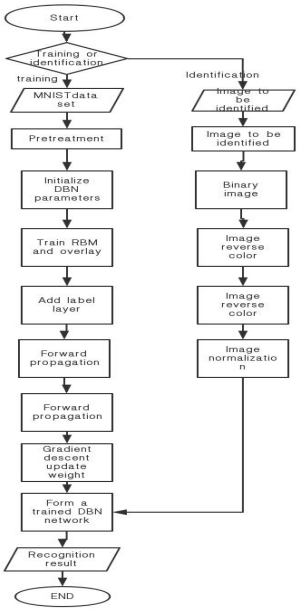

Figure 2.1 . Handwritten Digit Recognition Overall Algorithm Flow

2.1 Image Preprocessing

Network sample testing and evolution is achieved by parsing the data set. The tested images must be converted to binary files for storage, and these images are stored in the vector table in 784 dimensions. When using data sets in experiments, the main process of preprocessing is to process the grayscale, and the processing is normalized. In the mainstream mode, each picture is composed of 28*28 pixels, as shown in the Figure 2.2, in general, the recognition process is dominated by a number of factors, such as light intensity, which cause the original image to be unrecognizable, so there is a need to preprocess the data. The process requires segmentation of the image and processing of the grayscale. Finally, the image data is transformed into the deep belief network (pre-processed image) to draw conclusions.

This experiment selects the MNIST database of handwritten digits, available from this page, has a training set of 60,000 examples, and a test set of 10,000 examples. It is a subset of a larger set available from NIST. The digits have been size-normalized and centered in a fixed-size image.

It is a good database for people who want to try learning techniques and pattern recognition methods on real-world data while spending minimal efforts on preprocessing and formatting.The website is http://yann.lecun.com/exdb/mnist/.

IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

Figure 2.2 . Image Preprocessing

2.2 The Formation of DBN

The formation of DBN is the core process of the whole process. Start, start from the first RBM, do not monitor it, affirm its weight and offset; secondly, RBM is related before and after, the value of the previous RBM acts in the latter RBM, then the second RBM Store the data, and loop through the process to get the conclusion. Then, change the direction to the front and set the label layer to the top. The neural network forms a learning. This learning is an unsupervised learning. Finally, the direction is changed to the rear. RBM will be subject to the self-topping deviation from the reverse, reaching the goal of a brief adjustment of the DBN collection.

2.3 DBN Configuration and Training

The process of handwritten digit recognition is the process of identifying the DBN and identifying the DBN multiple times. For the use of deep belief networks, it is divided into multiple focuses. The choice of various data, as well as the multiple ways of identification, are detailed below. Activation of functions First of all, the choice of data is the most important. Selecting good data can prevent many problems. The problems that need attention are: (1) Nonlinearity: When there are other nonlinear functions in the process of activation, There is a problem: the formation of most of the activation functions is hindered, requiring a two-layer neural network to assist in the formation. However, the formation of the activation function is various. If there is an equal function in the formation of the activation function, the function of the neural network function of either one layer or two layers is very small. (2) Monotonicity: When a function is monotonic in the process of being activated and activated, its entire network can obtain a convex function for its network composition. (3) Differentiability: When the best solution is to gradually gradient its gradient When degraded, this activation function must be guaranteed to be differentiable. (4) Premise: When the function $f(x)\approx x$ is activated, if the random parameters with low initialization are added to the training, the test neural network with faster and more efficient speed can be obtained; if the preconditions are not met, only Carefully set the initial values to prevent errors. (5) Scope: The output of the activation function is ranged, and the gradient of the activated function is lowered to obtain an optimized more efficient value function. However, when the activation function does not have a range, although the speed of recognition and operation will increase, it will lead to a large drop in the learning rate.

2.4 Learning rate

There is an essential relationship between learning rate and error. The growth of learning rate is proportional to the growth of error, and the weight and weight error are also proportional. There are

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

two types of learning rate setting schemes, which are weight update and weight histogram, and the updated value of the weight is determined to be 0.001. Reducing the updated value of the weight is a good way to solve the weight increase.

2.5 Momentum Factor

Whenever the learning rate is increased, the convergence speed will also become larger, but it will also bring disadvantages. For example, the tested algorithm can not reach a stable state; reducing the learning rate can not only improve the stability of the algorithm, but also Can reduce the speed of convergence. The generation of the beam factor is to eliminate the errors and shortcomings caused by such problems. The purpose is to modify the way the parameters are determined. The direction of modification is determined by multiple schemes rather than the direction of the gradient, and the direction determined last time. And the direction of this determination is determined.

2.6 Dropout Parameters

When training the neural network model, when the training amount of the sample is reduced, the generalization ability of the network model is degraded (a fitting phenomenon occurs). In order to solve such problems, a parameter - Dropout parameter is introduced, the purpose of which is that the neural network invalidates some nodes of the hidden layer during the training process. The consequences of such fitting are solved. In theory, Dropout averages the model and invalidates the nodes of the neural network, so that the neural network obtains other models in the training process and finally obtains the average probability. But using the Dropout parameter also causes an increase in training time.

3 Experimental Design and Results

The working environment of this experiment was carried out in a Lenovo computer under the Windows operating system, and the software used was Matlab. The purpose of the experiment is to detect the optimal number of layers of DBN in the process of handwritten digit recognition and the analysis of Dropout parameters.

3.1 The Impact of DBN Presence Factors on Recognition Accuracy

When designing the neural network, first do not use the Dropout parameter, set the activation function to the sigmoid function, set the momentum parameter value and the learning rate to 0.5 and 1. respectively, and test the parameters of each layer separately (3, 4, 5, 6). Layer), respectively, to obtain the corresponding results. as the Figure 2.3 shows.

IETI Transactions on Engineering Research and Practice

http://ieti.net/TERP/

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

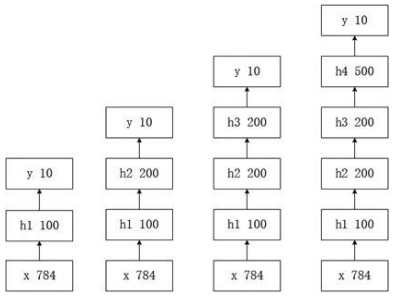

Figure 2.3 . DBN Test Results

3.2 The Impact of Dropout Training on Recognition Accuracy

The network initialization dropout parameter is determined to be 0.5, the sigmoid function is set to the activation function, and the layer number is set to 5 layers, the momentum parameter value is set to 0.5, and the learning rate value is 1, if 2 000 pictures are used for training, 1 000 For image testing, the error rate for using Dropout is 11%; the error rate for not using Dropout is increased to 13%. In the same environment, the number of samples increased by 60 000 and the number of samples trained for the sample increased to 10,000. The training error rate obtained at this time was 7 percent. Experiments show that selecting a small number of training samples will maximize the dropout parameter, which can minimize the side effects of the fitting effect. The increase of the training sample will lead to the drawbacks of the dropout parameter, the training sample increases, the dropout parameter effect decreases, and the training The time has also increased greatly.

4. Conclusion

Handwritten digit recognition In the process of applying DBN, a series of tests were carried out on its accuracy and optimal layer number. The best accuracy was obtained when the number of layers of the hidden layer reached 5 layers and the best accuracy reached 93.4. %, this experiment is higher than other experiments under the same conditions (handwritten digit recognition by SVM design). At the same time, this experiment also tests the influence of the selection of training parameters on the application effect of the dropout parameter. When the training sample is small, the effect of the dropout parameter is maximized. When the training sample is too large, the effect of the dropout parameter is significantly reduced. Moreover, the fitting phenomenon is generated, and the fitting phenomenon is determined to be the minimum when the value of the dropout parameter is determined at 0.5. Handwritten digit recognition is becoming more and more common in modern life and is an indispensable part of some industries.

http://ieti.net/TERP/

2019, Volume 3, Issue 1, 1-12, DOI: 10.6723/TERP.201908_3(1).0001

References

[1] Ren Xiaokui, Ding Xin, Tao Zhiyong, He Xinjian. A multi-classifier based non-segmented handwritten numeral string recognition algorithm [J/OL]. Computer application research: 1-6 [2019-07-11]. https://doi.org/10.19734/j.issn.1001-3695.2019.03.0097.

[2] Ye Xiaobo, Qin Haifei, Lu Yonglin. An improved Adaboost-BP algorithm for handwritten numeral recognition [J]. Journal of Dali University, 2019, 4 (06): 5-9.

[3] Cheng Renxin, Liu Junliang. Application of GA-BP Neural Network in Handwritten Number Recognition [J]. Electronic Measurement Technology, 2019,42 (09): 89-92.

[4] Ru Xiaoqing, Hua Guoguang, Li Lihong and Li Li. Handwritten numeral recognition based on deformable convolution neural network [J]. Microelectronics and Computer, 2019, 36 (04): 47-51.

[5] Zhu Juan, Chen Xiao. Improving the method of orderly overlapping handwritten numeral recognition in capsule network [J/OL]. Laser Magazine: 1-4 [2019-07-11]. http://kns.cnki.net/kcms/detail/50.1085.TN.20190326.1448.002.html.

[6] Han Ruichong. Research on Handwritten Number Recognition Based on Nearest Neighbor Algorithms [J]. Electronic Production, 2019 (06): 59-61.

[7] GAO Xue,WANG Youwang. Similar Handwritten Digit Recognition Based on CNN and Stochastic Elastic Deformation[J].Journal of South China University of Technology(Natural Science Edition),2017,(01):72-76.

[8] Ma Liquan, Li Wei, Cai Hanhui, et al. Research on preprocessing technology in handwritten digit recognition[J]. Chinese Journal of Scientific Instrument, 2016, 263-265.

[9]Meng Gengxiang, Fang Jinglong.Design of handwritten digit recognition system based on support vector machine[J].Computer Engineering and Design,2016,26(6): 1592-1594.

[10]Xiao Wei, Tan Yanghong. Handwritten digit recognition based on new feature extraction method and quantum neural network[J].Electronic Measurement Technology,2016(6): 84-87.

Author Introduction

Zefeng Li, a master of Data Science, City University of Macau, research directions: smart city, data analysis.

Han Ma, a master of Data Science, City University of Macau, research directions: machine learning, data mining and data analysis.