Improving Recognition Rate of Persian Handwritten Digits Classifier Using FCM Clustering and Inclined Planes System Optimization Algorithm

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***Abstract*— In this paper, a method is proposed to increase the recognition rate of the Persian handwritten digits classifier. A fuzzy method is used for classification in which there is just one fuzzy rule for each digit [1]. The number of Persian digits is 10, Therefore, the total number of fuzzy rules used in the base method is 10. After implementation, Where the number of fuzzy rules is ten, the recognition rate is 86.21 and 80.19 percent for training and testing samples, respectively. Clustering is used to increase the recognition rate. Training data related to each digit are divided into several clusters and one fuzzy rule is extracted for each cluster. Thus, the number of fuzzy rules is significantly increased (784 rules), since the recognition rate is also increased significantly, increase of fuzzy rules is acceptable. By applying this method, the recognition rate of training and testing samples is increased to 98.97 and 97.15 percent, respectively. FCM method is used for clustering. To select the optimal number of clusters for each digit, the inclined planes system optimization algorithm is used.**

***Index Terms*— Digits Recognition; FCM Clustering; Inclined Planes System Optimization (IPO); Persian Handwritten Digits.**

I. Introduction

Today's, clustering has been applied in various fields such as computational vision, machine learning, pattern recognition, mechanical engineering, electrical engineering, web mining, spatial database analysis, data recovery, gathering text document, image processing, medical science, life science, geology, astronomy, social science, and economics.

Also, many studies have been made on the recognition of Persian handwritten digits and letters in the field of academic research and also application and business areas; for instance, the studies [1-8] and [9-12] have been made in the field of academic research. For example in [10] Gradient histogram features, SVM classifier and the developed characteristic locus method were used in combination. In this method, the features that affect the recognition rate among all extracted ones were selected using an Improved New Binary Particle Swarm Optimization (INBPSO) algorithm in order to improve the recognition rate. The extracted initial feature vector included 400 features which were reduced to 64 after feature selection. HODA Farsi Digit Dataset was used.

In another method, binary SVM classifier and the HODA dataset were used for handwritten Farsi digit recognition [11]. In SVM, the One-vs-All (OvA) strategy was adopted. The feature extraction was performed using a two-dimensional wavelet transform and then feature reduction by PCA. Also, A novel smart handwritten Persian digit recognition method was proposed [12]. Using the smart method in the feature selection problem, the recognition rate was increased to an acceptable extent. A fitness function, optimized and minimized by Gravitational Search Algorithm (GSA), was the number of fuzzy classifier errors. The good recognition rate obtained without any preprocessing and post-processing. For more information, please refer to the mentioned references.

The most important applications of recognition of Persian handwritten digits or letters are: entering the information of administrative documents such as filled forms and checks, automatic identification of plate number for traffic control system, identification of written characters on the touch screen, controlling the system by drawing shapes, breaking CAPTCH, designing technologies to help the blinds and people with poor eyesight and so on. In the Persian language, there are many differences in the way of writing digits and also the digits are very similar to each other, thus creating a recognition system with high accuracy is difficult. In this paper, a method is provided for Persian handwritten digits recognition using FCM clustering and inclined planes system optimization algorithm that has high accuracy. A fuzzy classifier is used for recognition [1]; the aim is to increase the recognition rate of this classifier by using FCM clustering. In [1], one fuzzy rule is extracted for each digit; it means there is only 10 fuzzy rules. In this study, firstly training data of each digit are divided into several clusters by using clustering, and then a fuzzy rule is extracted for data of each cluster. Clustering increases the number of fuzzy rules and improves the recognition rate. The FCM method is used for clustering. To select the optimal number of clusters of each digit, inclined planes system optimization algorithm is used. IPO algorithm is a relatively new population-based optimization algorithm that it's presented by Mozaffari et al. in 1391 [13]; it has been used in [14] and [15].

The standard database "Hoda" is used for doing the tests [16]. This data set is derived from the entrance examination registration forms and the resolution of samples is 200 dpi. This database has 102352 digits in which 60000 digits are considered as training samples, 20000 digits as test samples and 22352 digits as remaining samples.

The samples of database digits can be seen in Figure1.

Figure1: sample of Hoda database digits

The structure of the paper is as follows. In section 2, the basic concepts are briefly presented including clustering, FCM clustering, inclined planes system optimization algorithm, feature extraction methods, and fuzzy classifier. In section3, the proposed method is introduced to increase the recognition rate. In section4, the proposed method is evaluated. Finally, the conclusion is provided in section 5.

II. Basic Concepts

A. Clustering

Clustering is an automatic process by which the data are divided into classes whose members are similar; each of these classes is called a cluster [17]. Different measures can be taken for the similarity between members, for instance, the distance measure can be considered for similarity and samples that are closer together considered as a cluster (clustering based on distance). It can be said that there is no absolute measure for the best clustering and it depends on the problem and user comment that use of which measure clusters properly the samples.

One of the most comprehensive classifications used for a variety of clustering methods is as follows [18]:

1-Partitioning methods 2- density -based methods 3-hierarchical methods 4- model-based methods 5- grid-based method

The most common and simplest method of clustering is the K-means algorithm which is classified as partitioning methods. This method is as a basis for other clustering methods, including FCM method that will be used in this paper. In K-means algorithm, the centre of each cluster is the mean of available samples in that cluster. This method is more efficient at large databases, but often gets caught in the trap of local optimal. In [19], various forms of K-means algorithm are provided that all of them have the same approach. In this paper, the FCM method is used for clustering that described in the next section.

B. FCM Clustering

FCM clustering is the generalized fuzzy clustering of K-means clustering algorithm in which the data points can be assigned to each of the cluster with degree of dependency between 0 and 1. The fuzzy clustering is more efficient in real condition because the samples in the border of different clusters are not forced to belong to one of the clusters perfectly. In other words, the membership is considered for each of data point for all clusters [20]. The aim of clustering process is to find the cluster centers and the dependency of each data point to that centre. Degree of Dependency suggests that a given data is to what extent dependent to a cluster. One of the most important issues in clustering is the selection of optimal cluster number.

The number of cluster is selected in a way that firstly the samples in one cluster are as similar as possible; secondly the samples in different clusters are as dissimilar as possible. The number of cluster centers is selected by two general methods. In the first method, the number of cluster centers is determined before clustering; this method is called supervised clustering. In second method, the number of clusters is determined during clustering; this method is called unsupervised clustering. Today's, clustering as an unsupervised learning method is more efficient in many issues. Result of clustering process is the set of membership functions as shown below. [21]

$$\sum_{i=1}^{c} \mu_{i,k} = 1 \tag{1}$$

where K in equation (1) is the number of evaluated data points that their set of membership functions values is equal to (2).

$$\sum_{k=1}^{n} \mu_{i,k} > 1 \tag{2}$$

The most commonly used method for fuzzy clustering is provided in [22] that its steps are as follows:

1. Random selection of cluster centers
2. Selecting the amount of membership of each data point to the cluster centers in a way that the general conditions are met.
3. Calculating the amount of membership of each data point to the cluster centers.

$$U_{ik} = \frac{1}{\sum_{j=1}^{c} \left(\frac{d_{ik}}{d_{jk}} \right)^{1/m-1}} \tag{3}$$

4. Calculating the next values of cluster centers according to the following formula:

$$v_i = \frac{\sum_{k=1}^{n} U_{ik}^{m} X_k}{\sum_{k=1}^{n} U_{ik}^{m}} \tag{4}$$

5. Repeating step 2 to 5 if the calculated value for centers is not different from its previous values.

One advantage of FCM algorithm is that converges to an optimal point. FCM objective function is defined as follows:

$$J(U,V) = \sum_{i=1}^{c} \sum_{k=1}^{n} u_{ik}^{m} d_{ik}^{2} = \sum_{i=1}^{c} \sum_{k=1}^{n} u_{ik}^{m} \left\| x_k - v_i \right\|^2 \tag{5}$$

After the general condition of the problem, $\sum_{i=1}^{c} \mu_{i,k} = 1$ was considered, the values of membership function and cluster centers are calculated with equation (6) and (7).

$$v_i = \frac{\sum_{k=1}^{n} U_{ik}^{m} X_k}{\sum_{k=1}^{n} U_{ik}^{m}} \qquad (7)$$

C. Feature Extraction methods

Selecting the feature extraction method is one of the most important and effective steps in a pattern recognition system. Different features such as zoning features, Geometric moments, Zernike moments, instant descriptors, invariant moments, histogram display, projections, features of characteristics of places, krish, border profile, gradients, gradient histogram, etc. have been used[1-8], [9]. In this study, the characteristics of places and zoning features are used for recognition. The result related to the zoning feature is better than the characteristics of places feature which report in the following.

D. Fuzzy Classifier

There are 10 rules in the introduced Fuzzy system in reference [1]; in which each rule recognizes each digit. An example of these rules can be seen in the reference [1]. The Fuzzy set $A_{i,j}$ is obtained from training samples [1]. The algebraic multiplication is utilized for "and" operator.

E. Inclined Planes System Optimization (IPO) Algorithm

Inclined Planes system Optimization algorithm (IPO) has been presented by Mozaffari et al. in 1391[13]. This method is inspired by dynamic motion of Spherical objects along a frictionless inclined surface in which all of these objects tend to reach to the surface lowest point.

In this algorithm, some of small spheres seek the search space to find the optimal point. These small spheres are like the particles in Particle Swarm Optimization algorithm or masses in Gravitational search algorithm. In this algorithm, one height is assigned to each of small spheres; the height is measured relative to a reference point. The height is calculated through the fitness function. These values are an estimate for the potential energy of spheres that are located at different heights. By reducing the height, the potential energy is converted to Kinetic energy which results in accelerating the spheres downward. It means that spheres tend to lose their potential energy in order to achieve to the optimal point (here minimum). So, spheres are frequently moving on the search space to find better response and proportionally get acceleration (Figure2).

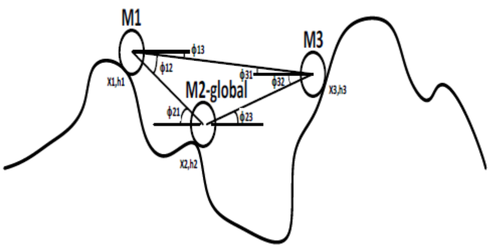

Figure 2: Example of search space with three spheres and an estimate of inclined plane

Each sphere has three coordinates in the search space: the position, height, and angle that it makes with other spheres. The position of each sphere is an answer to the problem's search space. To have an estimation of inclined plane in which spheres are located, the straight lines are used which

$$U_{ik} = \frac{1}{\sum_{j=1}^{c}\left(\frac{1}{d_{jk}^{2}}\right)^{\frac{1}{m-1}}} \cdot \left(\frac{1}{d_{ik}^{2}}\right)^{\frac{1}{m-1}} = \frac{1}{\sum_{j=1}^{c}\left(\frac{d_{ik}^{2}}{d_{jk}^{2}}\right)^{\frac{1}{m-1}}} \qquad (6)$$

connect the centers of the sphere. These lines make an angle with the horizontal straight line passing through the center of sphere by which the direction and amount of assigned acceleration to each sphere are determined. Consider a system with N spheres; the position of I sphere is defined by the following equation:

$$x_i = (x_i^1, \ldots, x_i^d, \ldots, x_i^n), \qquad for\, i = 1,2,\ldots,N \qquad (8)$$

$$x_j^{\min} \le x_j \le x_j^{\max}, \qquad 1 \le j \le n \qquad (9)$$

In this equation, x_i^d is the position of i sphere in the d dimension at the n-dimensional space. The aim of finding the f(x) position is the objective function minimum which is defined on the search space. The angle between i and j spheres in d dimension at t time, i.e. $\varphi_{ij}^{d}(t)$ is obtained from the following equation:

$$\varphi_{ij}^{d}(t) = \left[\tan^{-1}\left[\frac{f_j(t) - f_i(t)}{x_i^d(t) - x_j^d(t)}\right]\right] \qquad (10)$$

For $d = 1 \ldots n$ and $i, j = 1,2,\ldots,N,\ i \ne j$

So that $f_i(t)$ is the objective function value (height) for I sphere at time t.

Each sphere has an acceleration to slide on the inclined surface (search space) that is obtained from the following equation:

$$a = g.\sin(\varphi) \qquad (11)$$

In this equation, g is the gravitational acceleration constant and φ is the angle between the inclined and horizontal surface. In this algorithm, the value and direction of acceleration for I sphere in d dimension at time t are calculated through the following equation:

$$a_i^d(t) = \sum_{j=1}^{N} U(f_j(t) - f_i(t)).\sin(\varphi_{ij}^{d}(t)) \qquad (12)$$

$$U(w) = \begin{cases} 1 & w > 0 \\ 0 & w \le 0 \end{cases} \qquad (13)$$

In equation 12, constant g is removed from the equation to reduce the computations. IPO uses the equation of motion with constant acceleration to update the position of the spheres.

$rand_1$ and $rand_2$ are two random constants which distribute uniformly in interval (0,1) to give the random features to the IPO algorithm. $v_i^d(t)$ is the speed of I sphere in the d dimension at time t. To control the searching process of algorithm, two important constants K1 and K2 are used. These two constants are the function of time. With the passage of time, K1 original value should be reduced and K2 increased. These two constants create a compromise between the extraction and exploration concepts in the algorithm.

$v_i^d(t)$ Is calculated as follows:

$$v_i^d(t) = \frac{x_{best}^d(t) - x_i^d(t)}{\Delta t} \tag{15}$$

Where x_{best} sphere has the lowest height (fitness) in total iterations to the current iteration.

IPO algorithm is expressed at 8 steps as follows:

Step 1: Generating the initial population randomly, the values of initial parametersK1 and K2 and other parameters
Step2: iteration for each sphere
Step3: Calculating the fitness function for each sphere
Step 4: Calculating the angle, acceleration and speed for any sphere according to 3, 5 and 8 Equations
Step5: Updating the position of each sphere with Equation (7)
Step 6: Calculating and determining the K1 and K2 (a, ∅, v) values for each sphere
Step 7: Returning the spheres out of the search space into the search space
Step 8: when observing the stop condition is observed, the algorithm ends
Step 9: Position of the best sphere will be reported.

F. Exploration and Extraction in IPO Algorithm

The concept of exploration and extraction are two basic concepts for heuristic algorithms that allow them to seek the search space with the highest possible efficiency without sticking in local optimization in order to find the answer to the problem. The concept of exploration enables the algorithm to seek the entire search space by finding new places (such as mutation operator in genetic algorithm), while the concept of extraction enables the algorithm to seek locally and centrally the optimal locations in order to find the best places (such as selection operator in genetic algorithm). Therefore, to achieve an optimal solution, a compromise should be existed between the concepts of extraction and exploration. Usually, one of the appropriate ways to make this compromise is that the effect of exploration concept should be more than the extraction in the first iterations of the algorithm; with the passage of time, the effect of exploration concept should be reduced and the effect of extraction in algorithm added [23].

III. Proposed Method

The basis of classification in the digits recognition system is based on a simple fuzzy method [1]. In this fuzzy method, one fuzzy rule is written for each class. Since the number of Hoda database digit are very high and has the great

$$x_i^d(t+1) = k_1.rand_1.a_i^d(t).\Delta t^2 + k_2.rand_2.v_i^d(t).\Delta t + x_i^d(t) \tag{14}$$

diversity, we decide that several rules are written for each class. For this purpose, the training samples of each class are divided into several clusters, and then one rule is written according to the available samples in each cluster. There are several clusters within each class and there are fuzzy rules to the number of clusters in each class. For example, the samples number of digit 9 is divided into 30 clusters and 30 fuzzy rules are written for this class or for example 98 fuzzy rules are written for digit 3. The difference between the clusters number in different digit is arisen from lack of uniformity in the type of digits writing. For example, most people write the digit 9 similar but they may write the digit 8 in different ways. As one can see, the number of fuzzy rules is significantly increased in this method; also, the recognition rate is dramatically increased, so increase of rules is acceptable. The obtained results confirm the mentioned matter.

FCM method is used for clustering. Determining the optimal number of clusters is done using population-based optimization algorithms. Inclined planes system optimization algorithm is selected from among these algorithms which is a relatively new algorithm. In this algorithm, each ball is a ten-dimensional vector whose dimensions (K0, K1… K9) determine the number of clusters per class.

According to each ball and part of the Hoda database training samples, the fuzzy recognition system is created, and then this system is tested on the other part of training samples. The recognition rate is considered as the fitness function of the ball; this is done for all balls in the IPO. According to fitness functions, angle, velocity and acceleration are calculated for each ball based on the corresponding formula. Then, the position of each ball is updated according to the formula. This process is continued to meet the stop condition of IPO algorithm (which is usually a certain number of iterations). The K-fold cross validation method with k=3 is used for creating and testing the recognition system for each ball. It means that creating and testing the recognition system is done in three stages. At each stage, two-thirds of training samples is used to create the recognition system and one-thirds is used for testing and calculating the recognition rate. Finally, the average recognition rate of these three stages is considered as the fitness function of the ball. The testing samples of Hoda database are used to calculate the recognition rate of final system in which the optimal number of clusters is determined and data points clustered.

Steps of Proposed Algorithm:

1- Clustering of training data of each digit (digit c) to the number of K_C clusters where C= 0, 1…9.
2- Digits features extraction (through zoning and place of characteristics)
3- Creating K_C fuzzy rule for each digit using training samples
4- Creating fuzzy recognition system with N rules where $N = \sum_{c=0}^{9} K_c$.

IV. Assessment of Proposed Method

To demonstrate the effectiveness of the proposed recognition method and its comparison with other methods, the simple fuzzy method in [1] with 10 fuzzy rules are implemented using Hoda database digits and the recognition rate of testing and training samples of this database is obtained. The results are reported in Table 1. Then, the proposed method is implemented by using Hoda database digits. The corresponding results are reported in Table 1 which confirms the proper performance of the proposed method. Table 3 shows the performance of recognition system on testing samples of Hoda database. To determine the optimal number of digits clusters, the convergence of inclined planes system optimization algorithm is given in Figure 3. Table 2 provides the optimal number of obtained clusters by using inclined planes system optimization algorithm. In this paper, zoning feature and characteristics of places are extracted from each digit for recognition. The results of zoning feature are better than the characteristics of places which are given in Table (1). A parameter called generalized strength is reported in Table 1 which is defined as follows:

Generalized strength= 1- ((the difference between the recognition rate of training and test digits)/ (the recognition rate of training digits))

The articles in the Persian handwritten digits have been based on different databases, and in many of these articles, pre-processing and post-processing operations are also carried out. So their comparison is not right.

Of course, excellent databases for digits and letters were developed during recent years, most notably the HODA Dataset for digits and the Online-TMU Database for distinct letters.

Table 4 includes the results of various methods used in the recognition of digits, that all of them use Hoda database data. Although some of these methods also have preprocessing and post-processing operations.

As shown in Table 4, the result of this paper is among the desirable results.

Table 1
Obtained recognition rate for testing and training samples with and without FCM clustering and characteristics of places and zoning feature

Recognition method	Recognition rate of test digits	Number of digits error related to test step	Recognition rate of training digits	Number of digits error related to training step	Generalized strength
Simple fuzzy method without clustering for Zoning feature	80/19	3962	86/21	8276	93/02
Simple fuzzy method without clustering for characteristics of places feature	75/45	4910	86/43	8142	87.03
FCM clustering and fuzzy method for Zoning feature	97/15	702	98/97	832	98/16
FCM clustering and fuzzy method for characteristics of places feature	82/33	3145	89/34	6510	92/15

Table 2
Optimal number of clusters for each class using inclined planes system optimization algorithm

Class	0	1	2	3	4	5	6	7	8	9
Number of optimal clusters	85	74	89	98	80	57	85	87	99	30

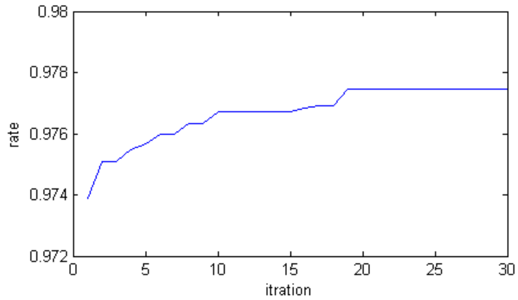

Figure 3: the convergence of inclined planes system optimization algorithm for determine the optimal number of digits clusters

Table 3
Performance of recognition system on testing samples of Hoda database

	0	1	2	3	4	5	6	7	8	9	The number of error	The percentage of error
0	1914	51	0	2	2	26	1	2	0	2	86	4.3
1	26	1931	3	1	5	2	3	0	0	29	69	3.45
2	0	1	1867	93	19	1	13	0	0	6	133	6.65
3	1	0	68	1877	47	1	4	0	0	2	123	6.15
4	2	1	4	118	1865	6	0	1	0	3	135	6.75
5	19	0	0	0	10	1969	0	1	1	0	31	1.55
6	1	3	1	2	6	4	1948	0	0	35	52	2.6
7	2	4	17	1	3	1	23	1948	0	1	52	2.6
8	3	1	0	0	8	11	1	0	1967	9	33	1.65
9	3	5	1	0	10	4	20	0	2	1955	45	2.25

Table 4
The results obtained by different digit recognition methods

Reference number	Feature extraction methods	Classification method	Recognition rate
[1]	Zoning	Fuzzy method	80.19
[10]	Gradient histogram and characteristic location	SVM	99.40
[11]	two-dimensional wavelet transform and PCA	SVM	91.75
[12]	Zoning	Fuzzy method	90.01
[this paper]	Zoning and characteristics of places feature	Fuzzy method and FCM clustering	**98.97**

V. Conclusion And Summary

In this paper, the effectiveness of FCM clustering on Persian handwritten digits recognition was examined. The obtained results indicated an improvement of the recognition rate of fuzzy system using clustering. Also, the optimal number of clusters was obtained by using inclined planes system optimization algorithm. Other optimization algorithms can also be used to select the optimal number of clusters. As shown, clustering increases the fuzzy rules that this leads to prolong the running time of algorithm, since the recognition rate is significantly increased, increase of rules is acceptable. The suggestion for further research is that clustering and feature selection can be used for the recognition of digits; by using clustering, one can increase The number of fuzzy rules and improves the fuzzy classifier. Then, one selects the effective features in increasing the recognition rate from among all features. Feature selection can be performed using the optimization algorithms such as IPO algorithm. However, using optimization algorithms need a lot of time for training step due to the iteration in these algorithms, but firstly this step is done only once and there is no need to do it in testing phase and secondly one achieve to the higher recognition rate by using these algorithms.

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