Integration of Fuzzy Logic, Particle Swarm Optimization and Neural Networks in Quality Assessment of Construction Project

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Abstract—**The current paper presents an approach that integrates soft-computing techniques in order to facilitate the computer-aided quality assessment of construction project. We confirmed the weight of each index quantitatively by mean s of Group-decision AHP according to an established index system. Then, we defined the elements of an assessment matrix using fuzzy and a quality assessment model for construction project is set up. The adoption of a particle swarm optimization (PSO) model to train perceptions in assessment and predicting the quality of construction projects in China. The Particle Swarm Optimization (PSO) technique is used to train the multi-layered feed forward neural networks to discriminate the different operating conditions. Comparing with back-propagation Artificial Neural Network (ANN) and ANN based on genetic algorithms, the simulated results of quality assessment of construction projects show that training the neural network by PSO technique gives more accurate results (in terms of sum square error) and also faster (in terms of number of iterations and simulation time) than BPN and GA-based ANN.**

Index Terms—**soft computing, particle swarm optimization, artificial neural network, quality assessment**

I. Introduction

Construction project quality management, the basis of construction management, is crucial for construction firms to survive and grow in the industry. Construction project quality assessment is one of the most important classes of quality management. The evaluation of the quality of construction is a typical multi-index evaluation. In practice, the evaluation of the construction project has a continuing nature, characterized by repetitive, frequent or regular, has many results of different cases accumulated, for example: national high-quality project evaluation, project quality evaluation in Beijing (Great Wall Cup) Award, as well as the internal selection of construction enterprises and the project's acceptance evaluation of department in charge of construction are regular or irregular carried on[1]. As practiced today, construction quality assessment and prediction generally relies on experts' intuitive experience. Scientific methods should be developed and employed during project planning and design stages in order to raise quality estimate and prediction accuracy.

At present, there are a number of integration assessment methods [3], for example, AHP, grey evaluation, fuzzy comprehensive judgment, AHP-fuzzy comprehensive judgment, etc. We should review all the assessment methods in order to find the most suitable method for assessing the quality level of a construction project. Some experts have studied these.

Artificial Neural Network (ANN) has outstanding characteristics in machine learning, fault, tolerant, parallel reasoning and processing nonlinear problem abilities[1]. It offers significant support in terms of organizing, classifying, and summarizing data. It also helps to discern patterns among input data, requires few ones, and achieves a high degree of prediction accuracy. These characteristics make neural network technology a potentially promising alternative tool for recognition, classification, and forecasting in the area of construction, in terms of accuracy, adaptability, robustness, effectiveness, and efficiency. Therefore, quality application areas that require assessment and prediction could be implemented by ANN. In recent years, the use of artificial neural networks, in particular, three-layer feed forward neural networks, which can be trained to approximate virtually any continuous function [1] becomes popular in practice. The application of artificial neural networks in the appraisal practice had many successful examples. Comparing the former assessment method, artificial neural networks has the following merit: (1) according to the data provided can discover the intrinsic relations between the input and the output through studying and training, thus has ability of study and auto-adapted function. (2) has exudes ability and the fault-tolerant ability. (3)suits in the processing non-linearity relations. Using the neural network to carring on the quality appraisal of the construction engineering, may

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use fully of the former case, obtain the appraisal knowledge. Thus, when faces group of appraisal data again, the consistent appraisal conclusion is obtained. In the essence, it has established the construction engineering quality appraisal system of study. Although the back propagation (BP) algorithm is commonly used in recent years to perform the training task, some drawbacks are often encountered in the use of this gradient-based method. They include: the training convergence speed is very slow; it is easily to gets tuck in a local minimum. Different algorithms have been proposed in order to resolve these drawbacks. The particle swarm optimization (PSO) firstly proposed by Eberhart and Fennedy [3,4,5], is a computational intelligence technique. Some researchers have used POS to train neural networks and found that POS-based ANN has a better training performance: faster convergence rate as well as a better predicting ability than PB-based ANN [5,6].

We carried out a comprehensive evaluation of a construction project using PSO-based neural network approach for assessment and prediction of the quality of construction project. First, we confirmed the weight of each index quantitatively by mean s of Group-decision AHP according to an established index system. Then, we defined the elements of an assessment matrix using fuzzy and a quality assessment model for construction project is set up. Then, the data were put into neural network for training, which using PSO for a better training performance: faster convergence rate as well as a better predicting ability than PB-based ANN. Finally, the trained system can be used to forecast the quality of construction project. The advantage of this approach is that it does not rely on the experience of experts an d it can improve the validity and the precision of evaluation. Consequently, it can reflect the quality status of construction project.

II. METHODOLOGY

A. FCE

Zadeh[7] first proposed Fuzzy Logic as a tool with which to describe uncertainty and imprecision. Because FL imitates the high- order mode in which the human brain makes decisions in the face of uncertainty or vagueness, it provides an effective way for automated systems to describe highly complex, ill-denied, or difficult-to-analyze subjects. In generals, Fuzzy Logic is composed of a fuzzier, rule base, inference engine and defuzzier [8-10].

- Suppose $U = \{u_1, u_2, \cdots, u_n\}$ is composed of evaluation index, $V = \{v_1, v_2, \cdots, v_n\}$ represent the evaluation factors.
- Suppose $A = (a_1, a_2, \cdots a_m)$ is the weight of the evaluation index,

Where $0 < a_i \le 1$, $\sum_1^m a_i = 1$

- Suppose comment set is $V = (v_1, v_2, v_3, v_4)$, and v_1 represent the grade is best, v_2 represent the grade is better, v_3 represent the grade is average, v_4 represent the grade is bad.

Fuzzy relation from to can be description as follow:

$$R_i = \begin{bmatrix} r_{i1} \\ r_{i2} \\ \vdots \\ r_{n_i} \end{bmatrix} = \begin{bmatrix} r_{i11} & r_{i12} & r_{i13} & r_{i14} \\ r_{i21} & r_{i22} & r_{i23} & r_{i24} \\ \vdots & \vdots & \vdots & \vdots \\ r_{in_i1} & r_{in_i2} & r_{in_i3} & r_{in_i4} \end{bmatrix} \quad (1)$$

Where r_{ij} $(i = 1,2,\cdots m; j = 1,2,\cdots n)$

- The fuzzy comprehensive evaluation can be got as follow:

$$B = A \bullet R \quad ..(2)$$

In this paper, the quality and grade of construction works are divided into four grades, namely: "best", "good", "qualified", "unqualified", and each grade score is 0.8, 0.6, 0.4, 0.1 respectively. So vector $C = [0.8, 0.6, 0.4, 0.1]^T$ is got. an evaluation of a quality rating score S_i was set up, so

$$S_i = B_i \times C \quad (3)$$

B. Overview of ANN

ANN is basically as implied model of the biological neuron and uses an approach similar to human brain to make decisions and to arrive at conclusions. Every neuron model consists of a processing element with synaptic input connections and a single output. The neuron can be defined as

$$y = f(W \times X + \theta_j) = f(\sum_{i=1}^{n} w_{ij} x_i - \theta_j)$$

where, x is input signals, ω_{ij} is synaptic weights of neuron, f is the activation function and y is the output signal of neuron as shown in Fig 1.

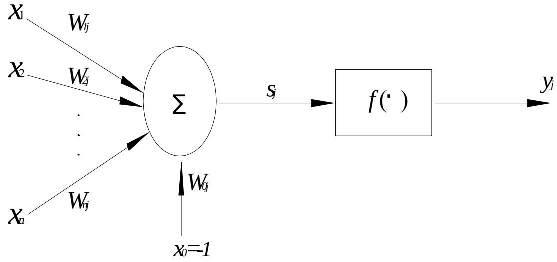

Figure1. The unit of processing

The architecture of multi-layered feed forward neural network is shown in Fig.1.

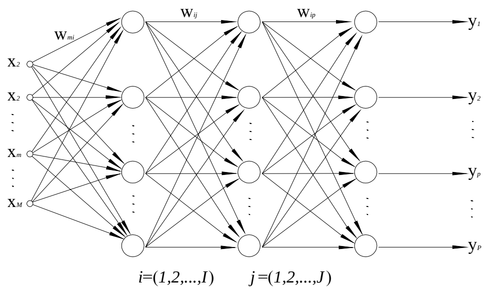

Figure 2. The model of BP net

It consists of one input layer, one output layer and hidden layer. It may have one or more hidden layers. All layers are fully connected and of the feedforward type. The outputs are nonlinear function of inputs, and are controlled by weights that are computed during learning process.

At present, the BP neural network is one of the most matures, wide spread artificial neural network. Its basic network is three-layers feed-forward neural network such as input layer, hidden layer, and output layer. The input signals must firstly disseminate forward into the hidden node. The output information of the concealment node transmits into output node Via-function action. Finally, the output variable result is obtained. The BP network can realize complex non-linear mapping relations will fully from input to output and has good exuding ability, which can complete the duty of complex pattem recognition

C. Overview of PSO Technique

PSO is an optimization algorithm, modeled after the social behavior of flocks of birds. PSO is a population-based search process where individuals initialized with a population of random solutions, referred to a particle are grouped into a swarm. Each particle in the swarm represents a candidate solution to the optimization problem and if the solution is made up of a set of variables , the particle can correspondingly be a vector of variables . In each one of the iterations, each particle is updated by following two "best" values. The first one is the solution (fitness) it has achieved so far. This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest[2,3,4]. After finding the two best values, the particle update its velocity and positions with Eqs. (2) and (3):

$$v_{id}^k = w_i v_{id}^{k-1} + c_1 \times rand_1 \times (pbest_i - x_{id}^{k-1}) + c_2 \times rand_2 \times (gbest_i - x_{id}^{k-1}) \quad (4)$$

$$x_{id}^k = x_{id}^{k-1} + v_{id}^k \quad (5)$$

Where w_i is the inertia weight, v is the particle velocity, x is the current particle (solution) , $rand_1$ and $rand_2$ are random numbers between (0,1) and c_1 and c_2 are learning factors.

Ⅳ. NEURAL NETWORK BASED ON PSO AND MOMENTUM

A. Defects of Classic BP Algorithm

The neural network based on BP algorithm through a simple compound function of neurons, allowing the network with nonlinear mapping capability, such a network without feedback, are belonging to feed forward networks. Despite the improvement in theory and a wide range of practicality deciding its important position in the artificial neural network, but the algorithm itself has also an unavoidable flaw. The main problems can be summarized as follows: (1) local minimum point, (2) Slow convergence, (3) It is difficult to determine hidden layers and hidden layer nodes, (4) The poor learning and memory of network.

B. The Improved BP Neural Network Algorithm

From the BP neural network algorithms and genetic algorithms speak its own characteristics, BP training algorithm is based on the error gradient descent mechanism that the weight inevitably fall into the local minimum points; PSO is good at global searching, and search for precision appears to be partial capacity Inadequate. So, in this paper, the PSO was used to optimize the weights of neural network.

(1) According to the defect slow convergence of BP algorithm, in this paper, we adopt the measures of added momentum to solve the problem, the principle is as follows: In practice, the choice of learning step is very important, in the other parameters remain unchanged, while learning rate big fast convergence, but too much may cause instability; small oscillation can be avoided, but the slow convergence to resolve this contradiction is the easiest way to join the "momentum of". Momentum is in each weight regulation to add a proportional to the weight of the previous regulation of the amount of value for:

$$\Delta w(n+1) = \eta \frac{\partial E}{\partial w(n)} + \phi \Delta w(n) \quad (6)$$

Where ϕ is the momentum coefficient, the general range is $[0,0.9]$. After adding momentum, the regulation of weight is made toward in direction of the bottom of the average, that is, momentum is played the role of buffer and gently, so that network convergence speed is regulated.

(2) The Best number of hidden nodes p : The network performance is impacted by the number of hidden nodes. when there is too many hidden nodes, it will lead to e-learning for too long, can not even convergence; and when there is less had hidden nodes, network has poor fault-tolerant capabilities. Best hidden nodes number p can be referred to the following formula:

$$p = (n+m)/2 + c \quad (7)$$

Where n is the number of input nodes; m is output nodes; c is constant between 1~10.

(3) PSO -based BP algorithms: BP network is one of the most widely used artificial neural network, is now

widely used in signal processing, pattern recognition, system identification, adaptive control and other fields. But its easy in a local minimum point is the Achilles heel of BP algorithm, and the genetic algorithm as a global search algorithm, and BP algorithm, has many advantages, such as the most easily into the local advantages, in the error function can not be micro-or no gradient information, particularly ineffective However, the genetic algorithm is also unable to avoid the shortcomings, such as genetic algorithm local search capabilities, it is difficult to select parameters, such as defects. Based on the above theory, this paper PSO algorithm BP algorithm and the respective strengths of the two organic combination of the completion of the common neural network weights and threshold adjustments.

The typical ranges of number of particles are 20-40 Actually formost of the problems 10 particles is large enough to get good results. For some difcult or special problems, 100 or even200 particles shall be tried. The ranges of particles for different dimensions of particles can be specied. The dimensions of particles are determined by the problem to be optimized. The optimized effect by the middle layer , The enlarged part of Fig.4, The optimized effect by inertial power, The optimized effect by the particle quantity and The optimized effect by memory unit were shown in Fig3. Fig4. Fig5. Fig6. and Fig7.

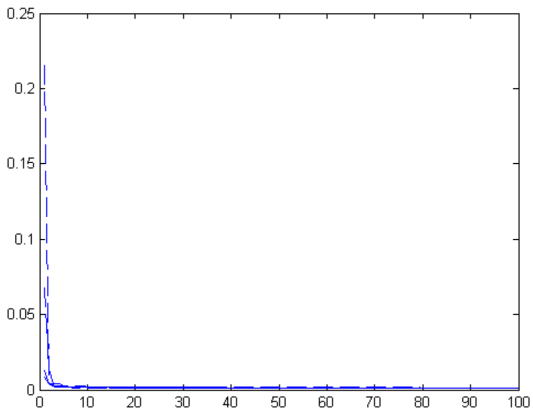

Figure 3. The optimized effect by the middle layer.

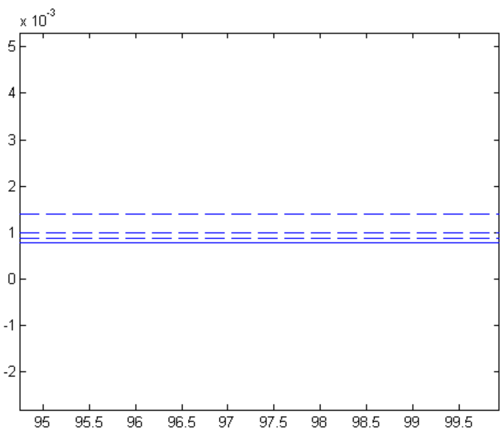

Figure 4. The enlarged part figure of 4-2

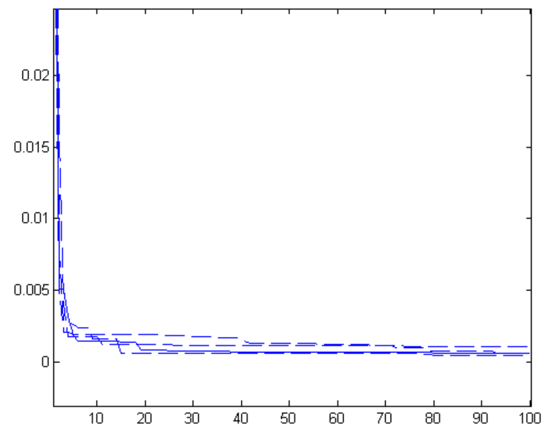

Figure 5. The optimized effect by inertial power

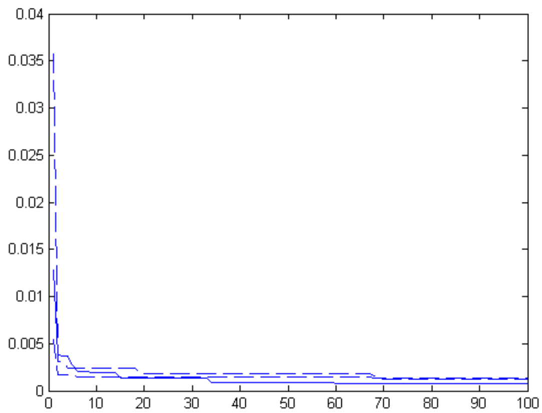

Figure 6. The optimized effect by the particle quantity.

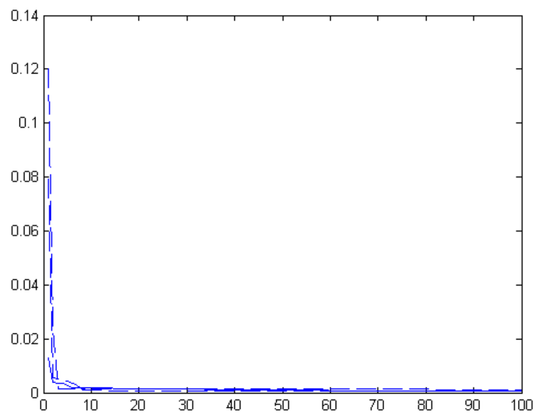

Figure 7. The optimized effect by memory unit.

III. Comprehensive Evaluation based on FCE-Group-decision AHP

It will take 15 projects as the evaluation object, and use the above method to evaluate the overall quality of projects and sort them. The assessment steps are as follows:

A. *The Establishment of Fuzzy Matrix*

According to the above unascertained measure synthetic appraisal model, we take one hundred typical enterprises in one certain region (supposed to object1)for example to evaluate synthetically. The number of the appraisal experts is ten. The appraisal index system is shown in Table 1.

The index set is {best, good, qualified, unqualified} and it is divided into five appraisal scales and by all appearances, it is positive sequence. The each factor is total ten score. Then, each appraisal object is ten score

TABLE I
THE SET EVALUATING QUALITY FACTOR APPRAISAL OF A ENGINEERING

First-Level Indices	**Second-Level Indices**	**Fuzzy Comprehensive Matrix**			
		Best(V_1 ***)***	***Good(*** V_2 ***)***	***Qualified(*** V_3 ***)***	***Unqualified (*** V_4 ***)***
Entity quality（u_1）	foundation engineering（u_{11}）	0.9	0.1	0	0
	main works（u_{12}）	0.8	0.2	0	0
	Building decoration engineering (u_{13})	0.7	0.3	0	0
	Roof engineering (u_{14})	0.8	0.2	0	0
	Water Building electricity (u_{15})	0.9	0.1	0	0
	Intelligent Building (u_{16})	0.9	0.1	0	0
	Ventilation and air conditioning (u_{17})	0.9	0.1	0	0
	Lift installation (u_{18})	0.8	0.2	0	0
	Built environment and Installation of outdoor (u_{19})	0.9	0.1	0	0
	Drainage and heating（u_{110}）	0.9	0.1	0	0
Quality assurance material（u_2）	Architecture and Structural Engineering（u_{21}）	0.8	0.2	0	0
	Drainage and heating (u_{22})	0.7	0.3	0	0
	Electrical installation (u_{23})	0.8	0.2	0	0
	Ventilation and air conditioning (u_{24})	0.7	0.3	0	0
	Lift installation（u_{25}）	0.9	0.1	0	0
	Intelligent Building（u_{26}）	0.7	0.3	0	0
Impression quality（u_3）	Architecture and Structural Engineering,（u_{31}）	0.8	0.1	0	0
	Drainage and heating（u_{32}）	0.9	0.1	0	0
	Electrical installation (u_{33})	0.8	0.2	0	0
	Ventilation and air conditioning (u_{34})	0.7	0.2	0	0
	Lift installation（u_{35}）	0.9	0.7	0	0
	Intelligent Building（u_{36}）	0.8	0.2	0	0
…	…	…	…	…	…
Influence on environment（u_5）	design phase（u_{51}）	0.8	0.2	0	0
	construction phase（u_{52}）	0.8	0.2	0	0
	service period（u_{53}）	0.8	0.2	0	0
	after the expiration（u_{54}）	0.5	0.5	0	0

and the distinguishment is that the degrees are different. The scoring principle is fit the measurement criterion. Based on the statistical data of the appraisal objects, the single measurement matrix can be got by Eq. (1).

B. The Determination of Weights

Weight set of indices can be got through group-decision AHP. The proportion of the scale of project' entity quality is determined by export analysis combining the analytic hierarchy process, as shown the following matrix:

$$E=\begin{bmatrix}1&2&3&3&3&3&3&3&3&3\\0.5&1&2&2&2&2&2&2&2&2\\0.33&0.5&1&1&1&1&1&1&1&1\\0.33&0.5&1&1&1&1&1&1&1&1\\0.33&0.5&1&1&1&1&1&1&1&1\\0.33&0.5&1&1&1&1&1&1&1&1\\0.33&0.5&1&1&1&1&1&1&1&1\\0.33&0.5&1&1&1&1&1&1&1&1\\0.33&0.5&1&1&1&1&1&1&1&1\\0.33&0.5&1&1&1&1&1&1&1&1\end{bmatrix}_{10\times10}$$

Solving Matrix Eigenvalue problems, $EA=\lambda_{\max}A$, got as follow:

$$\lambda_{\max}=10.01$$

$$C_I=\frac{n-\lambda_{\max}}{n-1}=\frac{|10-10.01|}{9}=0.001$$

$$C_R=\frac{C_I}{R_I}=\frac{0.001}{1.49}=0.0075<0.1$$

Therefore, the matrix meets the consistency requirements. The weight set of project' entity quality can be got as:

$$A=[0.24,0.15,0.08,0.08,0.08,0.08,0.08,0.08,0.08,0.08]$$

C. Comprehensive Evaluation

By Eq.(1), the evaluating matrix of fuzzy measure of single index is obtained as follows:

$$R=\begin{bmatrix}9/10&1/10&0&0\\8/10&2/10&0&0\\7/10&3/10&0&0\\8/10&2/10&0&0\\9/10&1/10&0&0\\9/10&1/10&0&0\\9/10&1/10&0&0\\8/10&2/10&0&0\\9/10&1/10&0&0\\9/10&1/10&0&0\end{bmatrix}$$

Using (2), the comprehensive evaluating matrix of fuzzy measure of entity quality is obtained as follows:

$$B=A\cdot R=[0.85,0.15,0,0]$$

By (3), the comprehensive evaluating score is got as follows:

$$S=B\times C=[0.85,0.15,0,0]\times[0.8,0.6,0.4,0.1]^T=0.77$$

Similarly, the appraisal of Quality assurance material, Impression quality, Design quality and Influence on environment are calculated as: 0.766， 0.77， 0.772， 0.766.

According to the similar method, obtain the result of fuzzy synthetic evaluation in other projects, the results are shown in Table2.

Ⅳ. QUALITY PRIDICTION WITH PSO-BASED ANN

A suitable assessment model is required to characterize the different operating conditions of construction quality. In construction engineering, quality assessment practices are usually carried out by department of construction

TABLE Ⅱ.
THE DATE EVALUATION ON ARCHITECTURE ENGINEERING QUALITY

No.	Quality Evaluation Indices					Evaluation Grade
	Entity quality	*Quality assurance material*	*Impression quality*	*Design quality*	*Influence on environment*	
1	0.77	0.766	0.77	0.772	0.766	Best
2	0.82	0.6789	0.76	0.812	0.781	Best
3	0.767	0.711	0.723	0.678	0.751	Good
4	0.645	0.711	0.658	0.642	0.711	Qualified
5	0.751	0.667	0.745	0.732	0.723	Good
6	0.623	0.724	0.699	0.711	0.689	Qualified
7	0.712	0.699	0.710	0.608	0.721	Qualified
8	0.758	0.832	0.865	0.812	0.766	Best
9	0.342	0.587	0.524	0.658	0.610	Unqualified
10	0.324	0.512	0.236	0.586	0.712	Unqualified
11	0.658	0.725	0.681	0.568	0.623	Qualified
12	0.711	0.628	0.756	0.812	0.645	Qualified
13	0.825	0.756	0.87	0.766	0.812	Best
14	0.785	0.658	0.845	0.688	0.845	Good
15	0.856	0.786	0.822	0.745	0.836	Best

quality management. The relationship between the quality influence factors and the quality grade, which is complex and nonlinear, is an important property of the quality of construction engineering. Such an application is modeled using SIMULINK (in MATLAB 6.1). This model allows simulation of faults and other disturbances that can lead to a false operation of the construction project quality forecast.

In order to assessment and forecast the quality of construction project, the 15 training samples data of Beijing city as shown in table 10 were collected as learning samples to input network. Among which the first 5 sets were training data and the last set served to verify the successfulness of the trained networks.

In this case, the network structure of ANN was 5-8-4 for input layer, hidden layer and output layer respectively. The population size was 200, 200 particles for the swarm. The inertia weight w was 0.3. The acceleration constants c_1 and c_2 were the same 2.0. The maximum velocity was 20 and the minimum velocity was -20. The maximum step of iteration was 500. In table 3, there were 5 nodes in the input layer, 8 nodes in the hidden layer, and 4 node that indict the output value of the quality value in the output layer, which indicted the quality grades. For those elements that are defined by several alternatives, for example, 'grade of quality' could be 'best', 'good', 'qualified' or 'unqualified', they are split into separate input elements, one for each alternative. Each alternative is represented in a binary format, such as '1' for remeasurement contract and '0' for the others if the type of contract is not remeasurement. In that case, only one of these input elements will have a '1' value and all the others will have a '0' value. In this way, the 4 elements are converted into an output layer of 4 neurons, all expressed in binary format. Table2 shows examples of the input neurons for cases with different types of quality.

The learning rate was 0.01, and expectative error was 0.001.Then the neural network was programmed by software Matlab6.1. The average variance EMS was 1.36521×10-5, and training time was only 0.566 second. The network model's training result was shown in Fig.8.

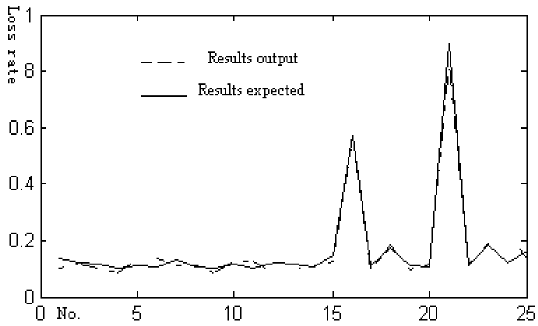

Figure 8. The training results

By using the trained neural network above, the quality of new construction projects were predicted. The results forecasted are in good agreement with the actual values as shown in Table3, and have been very accurate and meet the actual needs.

TABLE III
THE FORECASTING RESULT ANALYSIS OF QUALITY

No.	Results output				Results expected			
1	0.000033	0.00267	0.999958	0.000023	0	0	1	0
2	0.000027	0.00077	0.999966	0.000045	0	0	1	0
3	0.999941	0.00058	0.000031	0.000026	1	0	0	0
4	0.000038	0.99995	0.000019	0.000066	0	1	0	0
5	0.999981	0.00067	0.000034	0.000056	1	0	0	0

The performance of the PSO-based multi-layer ANN is benchmarked with a conventional BP-based network and GA-based network. Table4 and Table5 shows comparisons of the results of network for the three different perceptrons.

From Table4 and Table5, it can be observed that PSO-based ANN is best with the running times and the errors with the same running times. It can be concluded that the PSO-based perceptron performs better than the BP- based perceptron.

Ⅳ. CONCLUSIONS

Using the theory and method of fuzzy measure, the fuzzy model are established to analyze the evaluating indices and assess the quality of construction projects. By

TABLE Ⅳ.
THE RUNNING TIMES COMPARISON OF THREE ALGORITHM FOR XOR PROBLEM

Algorithm	Minimum times	Maximum times	Average times
BP	4444	5891	5214
GA	1024	2760	2314
PSO	565	921	847

TABLE Ⅴ.
THE ERROR COMPARISON OF THREE ALGORITHM WITH 200 TIMES

Algorithm	Best	Worse	Average
BP	0.4466	0.9981	0.7794
GA	0.0182	0.4071	0.1872
PSO	0.0079	0.1208	0.2437

comparing indicators values of every project, we can find relative weak places of quality then improve and enhance quality assurance measures. Take project No.10 for example, these indicators' values, such as "Entity quality", "Impression quality" are quite low. These aspects need to be improved.

This paper applies fuzzy comprehensive evaluation models and Group-decision Analytical Hierarchy Process in assessment of quality of construction project. Weight must be thought in the evaluation process. AHP is the first choice. The latter two models is objective. The unascertained function comes from measurement space and satisfies measurement criterions strictly. The indicator classification weight is calculated by given data, not by experts. FCM analysis provides evaluation criterions for the fuzzy measurement model, the two models combine perfectively. Using qualitative and quantitative analyses, the procedure overcomes the disadvantage of subjective and perceptual assessment. The demonstration analysis shows these methods can measure learning ability effectively. And it is easy to realize scientific and rational decision-making.

Construction project cost estimation and prediction is crucial for construction firms to survive and grow in the industry. This paper presents the application of a novel PSO-based perceptron approach for prediction of quality of construction project according to the characteristics of the construction project evaluation practice and the corresponding past appraisal decisions. It is demonstrated from the training and verification simulation that the proposed algorithm has a better ability to escape from a local optimum, a better training performance as well as a better predicting ability than the conventional PSO-based ANN in this case. It also shows that the prediction results of quality of construction project are more accurate and are obtained in relatively short computational time, when compared with the conventional BP-based and GA-based ANN perceptron.

It is demonstrated through this case study that it can serve the purpose of improving the performance of a neural network in the assessment of construction project quality. Owing to the flexibility of this approach, Other examples having similar characteristics with construction project quality might also be suitable for demonstration of the power of the PSO-based ANN.

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