Application of the GA-BP Neural Network in Earthwork Calculation

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Abstract. The calculation of earthwork quantity is the key factor to determine the project cost estimate and the optimization of the scheme. It is of great significance and function in the excavation of earth and rock works. We use optimization principle of GA-BP intelligent algorithm running process, and on the basis of earthwork quantity and cost information database, the design of the GA-BP neural network intelligent computing model, through the network training and learning, the accuracy of the results meet the actual engineering construction of gauge fan requirements, it provides a new approach for other projects the calculation, and has good popularization value.

1. Introduction

The earthwork engineering is one of the foundation engineering in the construction project. It takes a very important position in many engineering such as railways, hydropower engineering, urban planning, etc. The calculation of earthwork is the most important part of earthwork engineering. In order to estimate engineering costs accurately and speed up the progress of the project while enhance the quality of the project, we should calculate the amount of earth and stone accurately and optimize the deployment of earth and stone. Therefore, it is of great significance to study the intelligent calculation method of earthwork engineering.

Currently, the common calculation method of earthwork is square grid method, contour line method, section method, DTM method, etc. Each method has its own features and scope of application. Square grid method is the basic method of earthwork, suitable for large-scale flat area of earth calculation; the contour line method is suitable for the uniformity of the ground gradient and contour line closure; section method is suitable for the narrow striped area; if the data is allowed to use, then we can use the DTM method in any situation. The traditional calculation method of the earthwork always has low accuracy, and it has weak adaptability in three-dimensional complex terrain. In the calculation process, the manual calculation is too huge and can not improve the work efficiency through the computer.

With the development of optimization theory, intelligent algorithms are widely used. Such as genetic algorithm, artificial neural network algorithm, particle swarm algorithm, etc. These intelligent algorithms are realized by simulating the natural laws. Its advantages and mechanisms of the unique have aroused widely concern of domestic and foreign experts. Facing the accuracy requirements of three-dimensional complex terrain in earthwork, in the field of earthwork engineering calculation, the intelligent algorithm with high precision and strong applicability has not been research in depth. The
study in application of intelligent algorithms to calculate the amount of earthwork is helpful to improve
the precision of intelligent calculation of earthwork and can complete the amount of earthwork
engineering and its cost database.

2. Fundamental of Genetic Algorithm and Neural Networks
Genetic Algorithm is an intelligent calculation method for the genetic mechanism and natural selection
of simulated organisms in evolution. Mainly including selection, crossover and mutation operations and
has a strong global optimization performance. Back Propagation Neural Network which we can also
called the back propagation neural network, is a non-federated, non-interconnected network with three
or more layers, its structure is showed in figure 1. The Back Propagation Neural Network (Referred to
BP neural network) includes an input layer, one or more hidden layers, and an output layer in which all
the neurons are connected, and there is no connection between the neurons of the same layer. The
learning process of the training sample is running a cycle of the input signal forward delivery and the
error reverse delivery. To make the final output of the mean square error to meet the standard, the
training process will constantly adjust the connection weight.

![Figure 1. Three-layer structure of BP neural network](image)

The basic principle of using genetic algorithm to optimize the weight and threshold of neural
network is: According to the characteristics of the chromosomes in the genetic algorithm, the weights
and thresholds of the neural network are encoded and generate the Initial group; selecting the fitness
function, selecting the best chromosome as the neural network weight and threshold through the
genetic algorithm related operations, and screening individuals. Therefore, the combination of genetic
algorithm and BP neural network, first through the genetic algorithm on the neural network weights
and threshold optimization, narrowed the search range, and then use the BP neural network to solve
the problem.

3. Design of GA - BP Neural Network Model

3.1. Determination of Model Parameters

3.1.1. Coding and Generation of Initial Populations. We use real number coding the individuals,
encoding length is:

\[
S = n \times m + m \times l + m + l.
\]

In this formula, m is the number of hidden layers; n is the number of input layers; l is the number of
output layers.
3.1.2. **Determination the Number of Hidden Layer.** We select a BP neural network with one hidden layer for model design.

3.1.3. **Determination the Initial Weights.** The initial value of the model is a random selection of random numbers ((-1, 1) between random numbers).

3.1.4. **Determination the transfer function.** The transfer function of the hidden layer is the Sigmoid type function \( f(x) = \frac{1}{1+e^{-x}} \) as the node output function, its derivative is \( f'(x) = f(x)(1-f(x)) \), the advantage is that any input data can be converted into a number between \((0, +1)\).

Take the weights and thresholds obtained get from genetic algorithm into BP neural network and training.

3.1.5. **Determination of Fitness Function.** Set the fitness function to the reciprocal of the square sum of the neural network errors:

\[
    f = \frac{1}{SE}.
\]

In this formula, SE is the sum of squares of errors between the predicted output of the neural network and the desired output. Seen from the fitness function, the smaller neural network prediction error is, it will correspondingly to the greater fitness function and have better adaptability.

3.2. **Intelligent Algorithm Flow**

The specific steps of GA-BP neural network algorithm are as follows:

**Step 1** Network structure determination: According to the actual problem to be solved, we should determine the input and output variables of the BP neural network.

**Step 2** Pre-training: Pre-trained the BP neural network and then obtain the range of initial weights and thresholds.

**Step 3** Initial encoding: Encoded the initial weights and thresholds and determining initial population.

**Step 4** Determination of the fitness function: Calculate the sum of the squares of errors between the output value and the expected value of the BP neural network and use its reciprocal as a fitness function then calculate the fitness value \( f(i) \) of individual \( i \).

**Step 5** Judgment: Determining whether the individual fitness meet the optimization criteria, if yes then go straight to step 8; otherwise, do genetic operations in order.

**Step 6** Optimization of genetic algorithm weights and thresholds:

1) Select. Calculate the fitness values of individual individuals in the population and sort them. The probability value of selection is shown in (3):

\[
    p(i) = \frac{f(i)}{\sum_{i=1}^{N} f(i)}.
\]

In this formula, \( i = 1, 2, ..., N \) is number of chromosome.

2) Cross. Intersecting the crossover probability by using the arithmetic cross method.

3) Variation. Used non-uniform variation to change the probability of mutation.

**Step 7** Generation of new populations. Optimize the initial weights and thresholds by repeat Step3-Step6 until the optimization criteria meet the conditions.

**Step 8** The optimal solution and decoding of GA are optimized as the optimal weights and thresholds of BP neural network.

**Step 9** Do neural network training.

**Step 10** Neural network training ends.
4. Calculation Model of Earthwork Engineering Quantity Based on GA - BP Neural Network

The cost of the earthwork engineering and the main project volume depend on its engineering features. That is, there is a certain mapping relationship between the features of an earthwork and the engineering quantity: \( Mapping : T = \{ t_i \} \rightarrow Y \), Where \( T \) represents the engineering features of earthwork, and \( Y \) represents the amount of earthwork. We use BP neural network to analyze the mapping relation, and the model estimation result is used as the reference to test the accuracy of manual calculation.

4.1. Input and Output Design of GA-BP Neural Network

According to the existing earthwork engineering and quantity information database, we select a number (at least three) and the engineering which is similar to the proposed construction works; Based on the features of engineering cost and calculation of earthwork, the relevant data of characteristic factors are selected as training data for learning by neural network. Among them, seven factors such as actual elevation, design elevation, soil moisture content, soil dry density, possibility of loosen the soil, soil permeability and slope coefficient were selected as input layer. Engineering volume (where earthwork and stone as an output sample separately) as an output layer indicator.

a) The actual elevation:
We can obtain terrain elevation acquisition through field measurements or using the contour line by the insertion method.

b) Design elevation:
Field design elevation is the basis of the overall plan and the calculation of earthwork quantity.

The principles of design elevation determining: 1. Meet the requirements of the production process and transportation; 2. Make full use of terrain features, keep balance to fill the dug, to reduce the amount of earthwork calculations; 3. Have a certain slope to make sure we can drain; 4. We should consider the impact of the highest flood level.

The initial design of the site design elevation is only the theoretical value, in fact, we also need to consider if the soil can be loose, how to get the soil or spoil it and other factors to adjust.

c) Moisture content of soil:
The moisture content of the soil \( \omega \) is the ratio of the mass of water in the soil to the mass of the solid particles, if we expressed as a percentage that is:

\[
\omega = \frac{m_w}{m_s} \times 100\%.
\]  

(4)

In this formula, \( m_w \) is the quantity of water in the soil; \( m_s \) is the quantity of solid particles in soil. the degree of soil dry and wet is expressed by moisture content: If \( \omega \) is below 5%, called dry soil; If \( \omega \) is between 5% and 30%, called wet soil; If \( \omega \) is more than 30%, called saturated soil.

d) Dry density of soil

Mass of solid particles per unit volume weight of soil known as dry soil density, we can use \( \rho_d \) to represent dry density of soil:

\[
\rho_d = \frac{m_s}{V}.
\]  

(5)

In this formula, \( m_s \) indicates the mass of the solid particles in the soil; \( V \) indicates the natural volume of the soil. The dry density of the soil is often used as the standard for assessing the degree of soil tightness to control the compaction of the foundation pit and the compaction quality of the filling engineering.

e) Possibility of loosen the soil:

After the excavation of the soil, the volume of the soil increases due to the loosening, but the volume can not be restored after filling back and compaction, we called this property possibility of loosen the soil. The degree of porosity of soil is expressed by the coefficient of relaxation, that is
\[ K_s = \frac{V_2}{V_1}. \]  
\[ K'_s = \frac{V_3}{V_1}. \]  

Among them, \( K_s \) is the initial soil loosening coefficient; \( K'_s \) is finally soil loosening coefficient; \( V_1 \) is soil under the natural condition of the volume; \( V_2 \) is soil volume in loose state excavated; \( V_3 \) is soil compaction by volume.

\( f \) Permeability of soil

The permeability of soil refers to the degree of difficulty of water flowing through the pores of soil. The ability of water to penetrate the soil layer in unit time is called permeability coefficient, expressed by \( k \), and the unit is \( m/d \).

\( G \) Slope coefficient

In the excavation of foundation pit, groove or filling embankment, in order to prevent collapse, and ensure the safety of construction and slope stability, the slope should be considered on the slope. The slope of the earthwork slope is expressed by the ratio of its height \( h \) and the bottom width \( b \), that is

\[ \text{Earthwork slope} = \frac{h}{b} = \frac{1}{m} \]  

indicates slope coefficient.

4.2. Determine Network Structure

We adopt three layers of network training, according to the input samples to determine the node in the input layer is seven, the number of hidden nodes is selected according to the empirical data, the output layer nodes is two, the accuracy of network training requirements. The hidden layer adopts hyperbolic tangent Sigmoid function as the transfer function, and the output layer uses linear function as the transfer function.

4.3. Network Training and Prediction

The establishment of earthwork construction cost information database, using the general program Matlab programming algorithm of neural network learning calculation of earthwork. In the program design, mainly to achieve the following functions: data preprocessing, neural network and genetic algorithm to establish and initialize the weights and threshold optimization, neural network learning and training and BP neural network simulation and test.

Input learn basic data input training neural network, then design the learning rate is reasonable, in accordance with the modeling procedure and determine the structure and parameters of network training repeatedly, until the network error \( E < 0.0005 \), getting the earthwork training results; and then repetition the above steps, the amount of rock engineering training results were obtained; finally, we should calculate error ratio and analysis training accuracy.

After a certain number of iterative operations, it can effectively improve the accuracy of earthwork calculation results. After the neural network training, the test data of the test sample is input into the trained neural network for simulation test, and after the output value conversion processing, the final calculation results are obtained. When the model is running, the sample data can be filled out according to table 1, and the corresponding training results can be recorded.
Table 1. Sample data and training results of BP neural network model

| Serial number | Name of engineering | Training sample 1 | Training sample 2 | Training sample 3 | Test sample 1 | Test sample 2 |
|---------------|---------------------|-------------------|-------------------|-------------------|---------------|---------------|
|               | actual elevation    |                   |                   |                   |               |               |
| sample input  | Design elevation    |                   |                   |                   |               |               |
|               | water content       |                   |                   |                   |               |               |
|               | dry density         |                   |                   |                   |               |               |
|               | Porosity            |                   |                   |                   |               |               |
|               | Permeability        |                   |                   |                   |               |               |
|               | Slope coefficient   |                   |                   |                   |               |               |
| sample output | Earthwork           |                   |                   |                   |               |               |
|               | Rock                |                   |                   |                   |               |               |
|               | Net-work            |                   |                   |                   |               |               |
|               | Earthwork           |                   |                   |                   |               |               |
|               | Rock                |                   |                   |                   |               |               |

4.4. Model Characteristics

a) The amount of earthwork and actual elevation, design elevation, soil moisture, soil dry density and deformability of the soil, soil permeability and slope coefficient and other factors exist between the relationship between the GA-BP neural network through the network learning and training can effectively and accurately describe and quantify this complex relationship, the estimation results can meet the accuracy requirement, the method is extended to significantly reduce the project cost of the project, has guiding significance for other engineering calculation.

b) The intelligent calculation model of earthwork volume is established based on GA-BP, which provides real and reliable data support for further engineering cost. In practice, we should accumulate the known samples of earth and stone works, so that the accuracy of calculation can be improved continuously. When some characteristic data are not obtained due to special reasons, it is feasible to use the above method to estimate. In a word, it provides a quick, simple and scientific method for engineering cost personnel.

5. Practical application of GA-BP earthwork intelligent algorithm

5.1. The Premise of Intelligent Algorithm Application

The calculation method not only relies on the high precision intelligent GA-BP neural network based on the earthwork, before its application it needs the early stage of software development, and other preparatory work, including the calculation of test program and calculation model.

5.1.1. Compiling Calculation Program. Before applied the calculation model, first we work out with C++ language to establish neural network model of earth and rock volume calculation optimized by Matlab genetic algorithm, and run the source program in the environment of Visual C++ 6.

5.1.2. Test Calculation Model. Through the example of fuse genetic algorithm and neural network then apply it to earthwork calculation; we can verify the feasibility and effectiveness of the proposed GA-BP algorithm.

Design test function. The purpose of choosing the problem test set is to test the performance and efficiency of the intelligent computing method, and according to the test results to enhance the verification algorithm. Therefore, a number of test functions can be selected as test cases and tested.
Analysis and test results. Analyzing the test results, including the performance of the algorithm in convergence and diversity, then we can obtain the evaluation of algorithm performance. If the performance of the algorithm is low, then we should analyzed the reason according to the test results, and improved the algorithm further.

5.2. Prospect of Intelligent Algorithms Application
The intelligent calculation model of earthwork quantity established can be applied to the earthwork of different geological conditions, and it requires the data of 7 factors, such as actual elevation, design elevation, soil moisture content, soil dry density, soil porosity, soil permeability and slope coefficient can be obtained.

Currently, the genetic algorithm and neural network theory research has been relatively mature, and it has been widely used in engineering practical. The further integration of intelligent algorithms in engineering applications is a new development trend, the neural network intelligent calculation model of earthwork which based on genetic algorithm is not only applied to the calculation of earthwork quantity, we should extended the calculation method to the breadth and depth, to make it further tested and optimized, which has good application and development prospects.

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