Comparative Research on GPS Height Fitting Methods based on Neural Network

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Abstract

Characteristics and precision of BP neural network, genetic neural network and annealing neural network applied in GPS height fitting were hereby compared and analyzed to improve the precision of transforming GPS geodetic height into normal height. The results indicated that Genetic Neural Network method is superior to BP neural network method as well as Annealing Neural Network method with good precision through several instances.

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KeyWords: GPS Height Fitting; Precision; BP Neural Network; Genetic Neural Network; Annealing Neural Network

1. Introduction

GPS survey technology has attracted wide attention from the surveying and mapping industry since it was created by virtue of advantages such as high-precision positioning, fast surveying and easy operation. A lot of practice proves that GPS positioning technology is capable of completing high-precision 3D survey, with the accuracy of relative flatness positioning of $0.1 \times 10^{-6} \sim 1 \times 10^{-6}$ or higher, which is incomparable by the normal technology. However, GPS height surveying is actually the geodetic height relative to WGS-84 Coordinate System, but not normal height relative to quasi-geoid applied in China. In practical engineering work, transformation shall be carried out in obedience to the relationship between geodetic height and normal height if normal height of some point is to be determined through GPS survey technology. That is, without consideration to plumb line deflection, transformational relation between geodetic height and normal height can be expressed as:

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Where:

$H = h + \xi$ \hspace{1cm} (1)

$H$—Geodetic Height; $h$—Normal Height; $\xi$ -- Height Anomaly

The high-precision normal height of GPS point will be obtained through GPS height survey if we can get the high-precision height anomaly $\xi$. But it looks impossible as we can hardly get the high-precision height. Therefore, how to obtain the high-precision height anomaly becomes the pivotal issue for calculating the high-precision normal height in the practical GPS height survey.

There are various methods available for transforming GPS geodetic height into normal height through calculating the height anomaly of GPS point, among which, gravity model, function model fitting, stochastic model and artificial intelligence are relatively hot nowadays. Even though a certain achievement has been realized by applying those methods, the result is not so ideal. It is still a hot issue for the surveying and mapping industry to work out the way to improve the actual precision for transforming GPS geodetic height into normal height. This paper compares and analyzes the characteristics and difficulties in regarding to the application of BP, genetic and annealing neural networks in GPS height fitting, and further discusses the precision of GPS height fitting under the foresaid three conditions through several instances.

2. GPS height fitting method based on neural network

2.1 BP neural network method

BP network is a typical feedforward network and comprised of input layer, output layer and several hidden layers. Neurons in two adjacent layers will be fully connected, while neurons in the same layer will not connect to each other, as shown in Figure 1.

The working process of BP neural network can be divided into two stages, i.e. the learning phase and the working phase. The learning phase is comprised of the forward propagation of input information and back propagation of errors. During the forward propagation, input information will be disposed layer by layer from the input layer to the hidden layer and finally to the output layer and the status of neurons in every layer will only cause effects on neurons in the next layer. If the actual output of the output layer is different from the output proposed in the given sample, the output error will be calculated and then it will be converted into the back propagation of errors, to send back the error along the original connection path. And the error will be minimized by modifying the weighted value of neurons in various layers. After a great number of sample learning, the connection weight of neurons in various layers will be fixed and then it can enter into the working phase, during which, only forward propagation
of input information is involved. Forward propagation during the working phase will be conducted as per the foresaid calculation method.

2.2 Genetic neural network method

Genetic algorithm is a global random search algorithm to solve complicated problems by simulating the biologic. In the algorithm, the problem space is replaced by the code space; and one iterative process will be established by taking fitness function as the evaluation basis & coding group as the evolutorial basis and realizing the selection and genetic mechanism through genetic manipulation of individual string in the group. In the process, by randomly recombining the key gene in the coded string, the new generation will be better than the old generation. Hence the individuals keep on evolving and gradually get close to the optimum and finally solve the problem.

The network structure, the initial weights, threshold, learning ratio and other parameters of BP neural network will be fully optimized through making use of the global search ability of genetic algorithm, to set up a better search space in the solution space. Then BP algorithm will be used to search the optimum solution of the small solution space. So that, an improved BP neural network algorithm based on genetic algorithm is formed.

2.3 Annealing neural network method

The simulated annealing neural network method is a heuristic random search method, and is used to find the optimum solution in the global solution space by keeping decreasing the temperature with a given initial temperature. It has the characteristics of probability jump, i.e., it has the possibility to jump from the local optimum and then tend to global optimum. So, based on the characteristics of the gradient BP algorithm and probability jump of the simulated annealing neural network, the BP algorithm is regarded as the main frame; while in the training process, the gradient search of BP neural network method is used, at the same time, the probability jump of the simulated annealing neural network is embedded to avoid the local minimum. In other words, the BP method is used as the main frame but will subject to the adjustment of connection weight as per the probability under certain condition, to make the weight jump out of the local minimum under a certain probability and finally achieve the global minimum.

3. Characteristics of neural network technology applied to GPS height fitting

3.1 Characteristics of BP neural network technology applied to GPS height fitting

- GPS height transformation based on BP neural network is a self-adapted non-linear mapping method without assumption and thus it is theoretically reasonable and is capable of reducing the model error and improving the accuracy of GPS height transformation.
- Because of the characteristics of fault-tolerance and self-adaptation of BP neural network, the sample which can stand for the height fitting characteristics of the local region shall be considered as practical as possible provided that relatively small amount of learning & training samples can be used for BP neural network, so that generalization ability of the BP neural network can be improved. In engineering practices, precision of GPS height fitting can be realized even though it is already known that amount of height control points is relatively small; and that is very important for reducing the filed work for height survey and improving the working efficiency [1].
- BP neural network has the limitations such as the convergence speed is slow and the objective
function is easily fallen into local minimum etc \[2\].

- The structure design of BP neural network is crucially important. Precision of GPS height fitting is greatly affected by the number of hidden layer nodes, initial weights, threshold and other parameters \[3\].

3.2 Characteristics of genetic network technology applied to GPS height fitting

- Superiorities of global search of the genetic algorithms can be effectively exerted by combining genetic algorithm with neural network, so that defects of BP neural network such as it is easily fallen into the local minimum can be overcome. The combination is characterized by fast computational speed and fine approximation capability[4].

- By using genetic algorithm to optimize BP neural network, the trend to falling into local optimal can be avoided and it is faster and of higher precision than the BP algorithm. However, the convergence rate becomes relatively slow in the later period. Therefore the approximation ability and its efficiency shall still be improved [4] .

- If genetic neural network is used for GPS height transformation, comprehensive consideration shall be given to the selection of crossover probability, mutation probability, population size, number of generations and other genetic parameters. When selecting GPS points for training set, the distribution of the point in the survey area, including the margin points in the survey area and the points in the area with distinct terrain variation, should be taken into consideration [5].

3.3 Characteristics of annealing network technology applied to GPS height fitting

Functions of annealing algorithm like global search and probabilistic leap can be fully exerted by making use of annealing network technology in GPS height fitting, so that the global search ability is improved and the convergence rate is accelerated[6][7]. The annealing network technology uses the BP algorithm as its main frame. In the training process of BP algorithm, the global search function of annealing network technology is fully applied, i.e. it has the probabilistic leap at the local optimum. Once the local minimum is realized and the temperature is decreased to a certain degree, the search is fully operated by BP method. At that time, the convergence rate will be relatively rapid if the gradient-based method is used for guiding the learning, so that the disadvantages of BP algorithm that it is easily fallen into local minimum and thus leads to long computing time can be conquered.

4. Effect analysis of neural network technology applied to GPS Height Fitting

To take the control network of a certain GPS project as example, effects and precision of different methods, including BP, genetic and annealing neural networks, applied to GPS height fitting tests, shall be analyzed respectively. There are in total 15 height control GPS points coincide with the bench mark. The distribution of the height control points is shown in Figure. 1.

Figure 1. Distribution of GPS Points
The GPS-measured geodetic height and the normal height data of leveling survey are listed in Table 1.

Table 1. GPS Control Network and Leveling Survey Achievements

| No. | Point | x/10km | y/10km | GPS Height h/m | Normal Height | Height Anomaly ζ/m |
|-----|-------|--------|--------|----------------|---------------|--------------------|
| 1   | 2001  | 4.85622| -1.57899| 10.485         | 8.313         | -2.172             |
| 2   | 2002  | 4.828626| -1.01313| 8.913          | 6.547         | -2.366             |
| 3   | 2008  | 3.748925| -0.74526| 8.616          | 6.107         | -2.509             |
| 4   | 2010  | 3.764185| -1.85043| 9.013          | 6.192         | -2.839             |
| 5   | 3015  | 4.627002| -1.62406| 7.792          | 5.586         | -2.206             |
| 6   | 3018  | 4.433584| -1.70073| 8.508          | 6.206         | -2.306             |
| 7   | 3027  | 3.942168| -0.62326| 8.314          | 5.851         | -2.463             |
| 8   | 3029  | 3.760029| -0.99222| 8.084          | 5.53          | -2.554             |
| 9   | 3032  | 3.769341| -1.57934| 10.835         | 8.062         | -2.773             |
| 10  | 3036  | 3.855493| -0.72881| 6.679          | 4.225         | -2.454             |
| 11  | 4043  | 4.580938| -0.89312| 7.247          | 4.758         | -2.489             |
| 12  | 4050  | 4.442349| -0.86697| 7.11           | 4.634         | -2.476             |
| 13  | 4075  | 3.915812| -1.23814| 12.042         | 9.321         | -2.721             |
| 14  | 4078  | 3.655339| -1.30021| 13.186         | 10.507        | -2.679             |
| 15  | 4081  | 4.147118| -0.92612| 7.263          | 4.682         | -2.581             |

The structure of BP neural network is designed as a three-layer feedforward neural network, including 3 neurons in the input layer, 5 neurons in the hidden layer, and 1 neuron in the output layer, with a learning rate of 0.01, the learning objective function of $10^{-3}$ respectively. The maximum training time is 10,000; the activation function in both the hidden layer and output layer is a $s$-type log function. Among the training points, ten are selected as training samples, and the rest 5 points are chosen as check points. The population size in the genetic algorithm is set as 15, the crossover and mutation probability are 0.3 and 0.02 respectively. The number of generations is 1000.

BP, genetic, and annealing neural networks are used for fitting tests based on the identical samples. The computation results are shown in Table 2.

Table 2 The Abnormal Error in Height Fitting

| Type | No. | Point | Height Anomaly /m | Residual of conicoid fitting /cm | Residuals of BP neural network fitting /cm | Residuals of genetic neural network fitting /cm | Residuals of annealing neural network fitting /cm |
|------|-----|-------|-------------------|---------------------------------|------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Training points | 1   | 2001  | -2.172            | -2.1                            | 1.2                                      | 0.9                                           | 1.0                                           |
|       | 2   | 2002  | -2.366            | 1.4                             | -0.2                                     | 0.8                                           | -0.1                                          |
|       | 3   | 2008  | -2.509            | 0.3                             | -0.8                                     | -1.1                                          | -0.8                                          |
|       | 4   | 2010  | -2.839            | -0.3                            | -1.9                                     | -1.2                                          | -1.8                                          |
|       | 5   | 3015  | -2.206            | 1.6                             | 1.2                                      | -0.9                                          | 1.2                                           |
Table 2 shows that it is feasible to use BP neural network for GPS height fitting. Further, its fitting precision is better than using conicoid. Effects of GPS fitting are quite better by making use of genetic neural network, which is of higher precision not only than common methods such as conicoid fitting but also BP neural network fitting, with stable fitting precision. In addition, the method of annealing BP neural network used in GPS height fitting also gets relatively favorable results, with high and stable fitting precision.

5. Conclusion

Conclusions are made and listed as follows by analyzing the characteristics and practical application of BP, genetic, and annealing neural networks in GPS height fitting.

Because of the non-linear mapping ability and self-adaptation and other such characteristics of BP neural network, it is feasible for GPS height fitting, with higher precision than conicoid fitting etc. However, its convergence rate is slow and it tends to fall into the local minimum. So the structure design of BP neural network is crucially important for the effects of GPS height fitting.

The genetic algorithm uses the group search technology and is characterized by good global convergence and implicit parallelism. With respect to the genetic neural network integrated genetic algorithm with BP neural network, it is superior to BP neural network when used in GPS height fitting, with faster convergence rate, and can effectively avoid the possibility to fall into local minimum and also improve the overall performance of the neural network.

The simulated annealing neural network is a heuristic random search method. The method is to find the optimum solution in the global solution space by keeping decreasing the temperature with a given initial temperature. Based on such characteristic, the BP neural network is optimized, and then the simulated annealing neural network is formed. When the simulated annealing neural network is applied in GPS height fitting, it is superior to BP neural network and the precision is improved.
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