A HIGH EFFECTIVE MONTORING DESIGN FOR STRUCTURAL DEFORMATION WITH THE ANNEAL NEURAL NETWORK

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ABSTRACT:

This paper offers an effective method for optimal monitoring design of structural deformation measurement with the artificial neural network. The anneal neural network algorithm for optimal monitoring design of structural deformation is derived, constraints and parameters needed are determined, and a numerical example of 18 measurement spots is tested. The result shows that the convergent speed is fast, also the monitoring ability is effective.

1. INTRODUCTION

Neural computation and artificial neural networks have seen an explosion of interest over the last few years, and are being successfully applied in many areas, in problems of prediction, optimization, classification or pattern recognition.

In the optimization aspect of neural network, the Hopfield-Tank neural network (HTN) (Hopfield, T., and Tank, D., 1985)and the annealed neural network (ANN) (Zurada, J. M., 1992) (Kirkpatric, S., 1984) are popularly used.

The Hopfield-Tank neural network has the advantages of rapid convergence. However, it usually converges at a local minimum value, not a global minimum value. Besides, many parameters must be determined when the Hopfield-Tank neural network is used to solve the optimal problems. These parameters can only be determined by the trial and error method. Therefore, it often takes much time to get satisfactory solutions.

Recently, the simulated annealing is suggested as a popular technology to solve the optimal problems. The simulated annealing is a probabilistic hill-climbing search algorithm. It combines the steepest slope method and random process to get the global minimum value of energy function.

The annealed neural network integrates the advantages of the simulated annealing and the Hopfield-Tank neural network algorithm. Owing to the accurate result and rapid convergence, it has often been used to solve the optimal problems.

In this paper, the annealed neural network is used to solve the optimal monitoring order of a structural deformation network.

2. ALGORITHM

2.1 Artificial Neutral Network

The artificial neural network consists of many artificial neurons. These artificial neurons simulate the biological neurons by mathematical model. Its input-output relationship can usually be represented by the function of the weighted status variables and the threshold values, as the following equation:

$$Y_j = f\left(\sum W_{ij} S_i - \theta_j\right) \tag{1}$$

where

Yj: the output value
f: the transfer function
Wij: the weight value
Si: the input status variables
θj: the threshold value

The transportation paths among the artificial neurons are called "connections". Every connection has a weight value Wij that can simulate the synapse strength between the i^{th} and j^{th} artificial neuron.

In the following sections, the algorithm of optimal measurement order for structural deformation will be derived. The input-output relationship for optimization can also be represented in the form of general neural network function as Equation (1).

2.2 Anneal Network Optimization

Take a structural deformation monitoring network as an example, it is necessary to obtain the deformation between different time. There are many various observation orders can be chosen for measurement network. The problem is how to get an optimal monitoring order?

The task of the optimal monitoring order is to minimize the total path length. The path length is determined by observation distance, observation efficiency and structural deformation. In the case of short distance, small deformation, good observation efficiency, the path length is short. On the contrary, in the case of long distance, bad path service, large deformation and bad observation efficiency, the path length is long.

The steps of optimal monitoring design of structural deformation network using ANN are described as follows:

(1) Status variables S_{xi}

The status variables S_{xi}, represents the order of observation. Their value can be given as follows:

S_{xi} = 1, if station x is the i^{th} observation.

0, if station x is not the i^{th} observation.

The matrix that consisted of S_{xi} is called "permutation matrix". In the permutation matrix, each row represents one station, and each column represents the order of observation.

The initial value of status variables Sxi is a random value. It represents the probability that the x station is the i^{th} order of observation. It will be approach to 0 or 1 through the iteration process. The latest status variables combine to form the permutation matrix that represents the order of observation.

(2) Status Requirements

The constraints for a measurement network observation are:

A. Each spots observed just for once.

B. Only one spot is observed at a time.

C. All spots are observed.

The task of the optimal design is: "To search an optimal monitoring path that maximum deformation"

(3) Energy Function

The energy function of the network will be set up, as follows:

A. To satisfy the constraint "each spot is observed just for once ", the following formula is given:

$$\sum S_{xi}=1.0 \tag{2}$$

B. To satisfy the constraint" only one spot is observed at a time", the following function is given to check:

$$\sum_{x}\sum_{i}\ \sum s_{xi}s_{yi} \tag{3}$$

If the above function satisfies the constraint, its value will be zero, otherwise its value will be greater than zero.

C. To satisfy the constraint " all s are observed ", the following formula is given:

$$\sum_{x}\sum_{i} s_{xi} = n \tag{4}$$

D. To evaluate the task of minimizing the total path length, the following function is given:

$$\sum_{x}\sum_{i}\ \sum_{y\neq x} L_{xy}S_{xi}(S_{y,i+1}+S_{y,i-1}) \tag{5}$$

where Lxy is the path length between the x and y spot. The value of the function is minimum at the optimal solution.

In conclusion, if both Equation (3) and Equation (5) have the minimum value, meanwhile both Equation (2) and Equation (4) satisfy their constraints, then the solution must be optimal.

In order to combine Equation (3) and Equation (5), the simplest method is to weight Equation (3) and Equation (5). The weighted function can be expressed by an energy function E:

$$E=\frac{B}{2}\sum_{x}\sum_{i}\sum_{y\neq x} S_{xi}S_{yi}+\frac{D}{2}\sum_{x}\sum_{i}\ \sum_{y\neq x} L_{xy}S_{xi}(S_{y,i+1}+S_{y,i-1}) \tag{6}$$

where B,D are weight parameters.

The energy difference ΔExi can be derived by energy function E.

$$\Delta E_{xi}=E(S_{xi}=1)-E(S_{xi}=0) \tag{7}$$

Substituting Equation (6) into Equation (7), A Exi can be written as:

$$\Delta E_{xi}=B\sum_{y\neq x} S_{yi}+D\sum_{y\neq x} L_{xy}(S_{y,i+1}+S_{y,i-1}) \tag{8}$$

(4) Network Variation

Since design variable Sxi is that probability the x spot be the i th observation order, it is proportional to Boltzmann probability function exp(-ΔExi/T) . Therefore let

$$S_{xi}=\frac{\exp(-\Delta E_{xi}/T)}{\sum_{J}\exp(-\Delta E_{xj}/T)} \tag{9}$$

where T is the simulated annealing temperature.

Equation (9) guarantees to satisfy Equation (2) and Equation (4).

By annealing the temperature T in the iteration process, the energy difference ΔE will converge. When the energy difference ΔE converges, the permutation matrix that consists of status variables ^x; may represent the optimal order of observation.

The above algorithm was presented by Van Den Bout and Miller(Van Den Bout, D.E., and Miller, T.K., 1988). However it is not a complete neural network model. To be a neural network model, the above algorithm is modified in the following way:

(1) The Derivative of Connecting Weight

The energy function in a neural network can be expressed **by** Equation (10)

$$E = -\frac{1}{2}\sum_{i}\sum_{j} S_i W_{ij} S_j + \sum_{j}\theta_j S_j \tag{10}$$

where E: the energy function

Si,Sj: the i, j th status variables

Wij : the weight values

θ j : the threshold value

Comparing Equation (6) with Equation (10), we can get the connecting weight value Wxiyi and the threshold value θ

Wxiyi= -B δ (i,j)[l - δ (x,y)] - DLxy[δ (j,i +1) + δ (j,i -1)]

θ xi=0 (11)

where δ (x,y) = delta function, if x=y, then δ (x,y) =1; otherwise, δ (x,y) =0 .

Wxiyi,=-B,if y$\neq$x and j=I,

=-DLxy, if ｜j-i｜=1, (12)

=0, else

The connecting weight matrix W is a 4 dimensional matrix. It is not easy to be solved. As a matter of convenience, W can be replaced by a 2 dimensional matrix whose element is also a 2 dimensional matrix.

(2) The Derivative for Iterative Formula of Status Variable.

Substituting Equation (10) into Equation (7), ΔExi can be written as:

$$\Delta E_{xi} = -\sum_{y}\sum_{j} W_{xiyi} S_{yj} + \theta_{xi} \tag{13}$$

To alter Equation (13) into the form of general neural network function, let

$$net_{xi} = \sum_{y}\sum_{j} W_{xiyi} S_{yj} - \theta_{xi} \tag{14}$$

So $net_{xi} = -\Delta E_{xi}$ (15)

And $S_{xi} = \dfrac{\exp(net_{xi/T})}{\sum_j \exp(net_{xj}/T)}$ (16)

Through this process and comparing Equation (14) with Equation (1), the algorithm of optimal observation order becomes the general neural network algorithm. The result of Equation (14) can be solved with ANN method. And the optimal observation order denoted as Sxi in Equation (16) can then be evaluated.

The detail procedures for optimal observation of structural deformation network using ANN method is concluded as follows:

A. Set up the energy function parameters B and D.

B. Input the total path length matrix.

C. Compute weight matrix Wxiyj and the threshold value θ xi by Equation (11).

D. Input the initial status variable matrix Sxi .

E. Input the initial temperature T.

F. Compute the updated status variable matrixSxi’ by Equation(16).

G. Compare｜Sxi’-Sxi ｜with the convergence value ε

If ｜Sxi’-Sxi ｜$\geqq \varepsilon$, .then decrease the temperature T by Equation (17).

T=r.T (17)

Where r = annealed coefficient, r$<$ 1 .

H. LetSxi=Sxi’ , and iterate from step E, until ｜Sxi’-Sxi ｜$< \varepsilon$

I. Output the latest status variable matrix Sxi ,which is used to represent the optimal observation order.

3. DISCUSSION

The energy function parameters B and D, the initial temperature T, and the initial status variable matrix Sxi can further be discussed in the following way:

(1) The energy function parameters B and D

Van den Bout and Miller set D=l, B=the maximum path length. The reason is that it can assure to obtain the legal solution.

To find out the proper values of B and D, hundred times of tests have been evaluated in this paper. The results show that the lower B value has more opportunity of reaching the design task and the case that let B= the average path length can usually produce the legal solution. Therefore, it is better that we use B=the average path length instead of *B*= the maximum path length, although it may take a risk of illegal solution in solving process. If the illegal solution is obtained, it can be easily found. All we have to do then is adjust the parameters B and D again to get the legal solution.

(2) The Initial Temperature T

The probability of the x station to be the i th observation order is determined by Equation (16). The

probability of each station is almost equal at high temperature T. When the temperature is slowly reducing down, the probability of a certain station will approach to 1.
The convergent speed is greatly influenced by the initial temperature. If the initial temperature is higher, then the quality of solution is better, but the convergent speed is slower. On the contrary, if the initial temperature is lower, then the convergent speed is faster, but the quality of solution will be worse.

(3) The Initial Status Variables

The initial status variables Sxi are produced by random process as the following formula(Cichocki, A., and Unbehauen, R., 1993):

$$Sxi=1/n+w(r-0.5)/n \qquad (18)$$

^where

r: the homogeneous random number between 0 and 1.
w: the disturbed coefficient.

4. NUMERICAL EXAMPLE

In order to show the application of the concepts presented in the previous sections, a numerical example is given here. A structural deformation measurement experiment(Y.S. Yang and C.L. Wu, 2006) has been chosen. This measurement network consists of 18 measurement spots distributed at possible deformation places.

(1) Configuration Description

The configuration of these 18 measurement spots is distributed homogenously as shown in Figure 1. The approximate coordinates of these monitoring spots are measured with the digital camera.

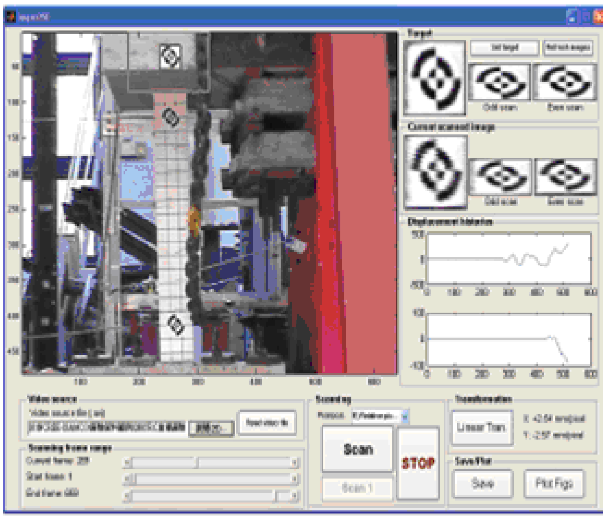

Figure 1. A image-based measurement program

(2) Input Data

The input data are as follows:

A. in order to converge faster, the coordinates of 18 observation spots are transformed into the range that from 0 to 1 by Helmert Transformation.

B. The path length Lxy is computed by Equation (19).

$$Lxy=DxyFxy/Bxy \qquad (19)$$

where

Dxy: the distance between x and y spot.
Fxy: the observation efficiency between x and y spot, it can be divided into three grades. If it is easy to observe, then Fxy =0.5 ; if it is fair to observe,then Fxy =1; if it is difficult to observe, then Fxy =2. In a special case,
if it is not intervisible, then Fxy=99 (Fxy= ∞ theoretically).
Bxy: the observation benefit between x and y spot, it can be divided into three grades. If there are many points can be observed by the spot,then Bxy =2; if there are a few points can be observed,then Bxy=1;
if there are few points can be observed, then Bxy =0.5.
if a certain station is pointed to observe next, then Bxy=99.

C. The initial status Sxi are computed by Equation (18) in which let n=18, r=*0.7890,* w=0.300.

D. The initial temperature T=1.0.

E. The energy function parameters B=1.80, D=1.0 .

(3) Result and Analysis

Using the modified ANN process, the result of optimal deformation measurement order is shown in Fig. 2.

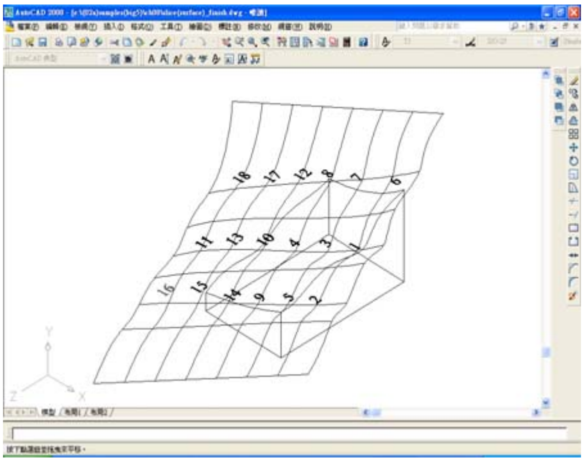

Figure 2. The result of the optimal deformation measurement order

This solution is evaluated as follows:

A. The spot measurement order stands for the degree of structural deformation .The more top of the order, the more large amount of the structural deformation. It is consistent with the practical case.

B. The first order is the first monitoring spot for structural safety. It is also consistent with the requirement.

C. It takes about 125 seconds to converge after a hundred iterations. Consequently it is rapid to complete the task.

D. When a monitoring order of structural deformation network is optimal designed, it needs n! selecting paths with the traditional algorithms, but it only needs n^4 selecting paths with the annealed neural network algorithm. For an example of 10 stations (n=10), it needs 3628800 selecting paths with the traditional algorithms, but only 10000 selecting paths with the neural network algorithm. Therefore, it can save much time to solve the optimal problem by the neural network, especially the more the number of stations, the more the time is saved.

5. CONCLUSION AND SUGGESTION

Neural network is a computer system that has been applied in many aspects recently. It can solve many complicate problems efficiently by using a large amount of simple connections of artificial neurons to simulate biological neurons. For the optimization aspect, two kinds of neural network algorithms are popularly used: the Hopfield-Tank neural network (HTN) and the annealed neural network (ANN). Because the HTN is limited by only obtaining the local minimum value and uneasy to determine the parameters, therefore it is better to use the ANN for practical application.

In this paper, the annealed neural network algorithm for optimal monitoring design of a structural deformation network is derived. In this optimal monitoring design, the constrains fitted to the practical measurement project are determined. The energy function parameters B and D values, the initial temperature T value, and the initial status variables' values are also suggested. From the numerical example presented in this paper, the result shows that the achieved solution is the globally minimum total path length. Meanwhile it is also able to be consistent with the practical deformation cases. Furthermore, it takes much less time for computation than the conventional methods. On the whole, the optimal ability of the neural network is good for structural safety..

Although the ANN has been proved to be an efficient method for solving the structural deformation problem, some parameters, such as energy function parameters and initial temperature, will affect the convergent speed. To find out the most proper values for these parameters, as well as the optimal monitoring design for other kind networks, are worthy for further study.

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