An Improved BP Neural Network Based on GA for 3D Laser Data Repairing

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Abstract— **Affected by scanning object, environment, scanning speed and user's operation .etc, some information of the object's surface can't be detected by the laser scanner. Aiming at the data loss in laser detecting , the paper presents an improved BP neural network based on GA for 3D laser data repairing, the novelty of this method is adopting Genetic Algorithm(GA) to optimize the configure and weight of network, and at the same time combining Back Propagation(BP) Algorithm to find optimal approximation. The simulation shows the improved BP neural network based on GA has a faster constringency speed and better repairing precision than traditional BP neural network and GA algorithm. Lastly, the paper gives the result of repairing the point cloud collected by 3D information reconstruction system using this network.**

Keywords— **Data repairing, GA, BP network, Laser scanner**

Ⅰ INTRODUCTION

The method of laser range has the obviously superiority compared with others, especially in recent years, the technology of laser scanner developed at high speed, so it is preferred for the application in distance detecting. But when using laser scanner detecting, because affected by scanning object, environment, scanning speed and user's operation .etc, the data collected from scanner is not integrated, the point cloud exists deformity, so the surface of object reconstructed according to the point cloud will exist hole, especially in the complicated object reconstruction.

Aiming at this problem, the scholars home and abroad did embedded researches, and presented some hole repairing method[1][2], for example, anciently data repairing generally adopted parabola tangential continuation method, but if the deformity area is big, the repairing precision cannot be ensured. In recent years, with the development of the technology of artificial intelligence (AI), it adopted in the calculation of approximation extensively. In [3], the author presents a method of data repairing using BP network, although BP network has the superiority in nonlinear approximation, restraining sample noise and repairing deformity data, BP network has the disadvantage in getting into local least easily and training slowly, and the result is not satisfactory.

GA derives form the genetic evolution theory of nature, and it has solved a lot of optimization question, its advantage is that it can get globally optimal solution even the function is polymorphic or discrete. There are a lot of researched on utilizing GA to build BP network home and abroad, they attempt to combine GA with BP network [4, 5, 6], in [7], the author present a Granularity-GA to optimize the network, this method can improve the precision, but it cannot avoid the best sample changing continuity of GA, and it will result in a low constringency speed. Yang Bo presents a network combined GA with BP, this method has a high precision and speed compared to individual GA or BP, but it can aims at some specially situation, it is not suitable for our 3D laser data repairing, because our 3D data is changing at a real time.

This paper presents a novel method on 3D laser data repairing, through combining GA with BP to design, the method holds the advantages of GA and BP, and specially in GA, it not only adjusts the weight but also the configuration of the network, this can make the algorithm to suit the different application in repairing hole. In the method of coding, we adopt a combination of binary and real number, it not only economizes the memory space but also improves the precision, the simulation shows that the method presents in this paper certainly has a obvious efficiency in both speed and precision, it is suitable for our 3D laser data repairing.

The paper is divided to into the following sections:3D laser scanning system(section Ⅱ), BP network and GA(section Ⅲ), GA-BP network in data repairing(section Ⅳ), and at last a simulation is presented to testify the improved BP neural network based on GA.

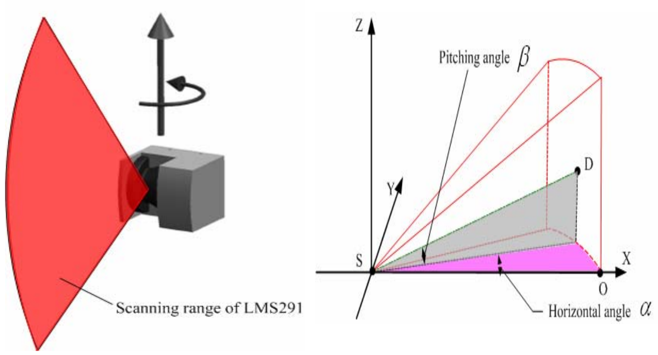
Ⅱ 3D LASER SCANNING SYSTEM

The data repairing algorithm is applied in a vision system of a mobile robot, the vision system mainly is a 3D laser scanning system, it consists of a 2D laser scanner LMS291 produced by SICK AG and a turning platform, as figure.1 shows. LMS291 is a 2D scanner and its distance detection principle is explained in paper [8]. In the vision system through the turning the platform, the scanner can get a 3D data, as figure.2 (a) shows.

Figure.1. The vision system based on LMS291

The data colleted from 3D

laser scanning system is in polar coordinate, and it is not convenient for data disposal, so we need to establish a Cartesian coordinate adopting lasing light emitter as the origin, the scanner can get distance between S and the object defined as SD and β , through platform we can get α , with α , β and SD, we can get the x, y and z coordinate of D in s-xyz coordinate, as figure. 2 (b) shows.



(a) (b)

Figure.2. The principle of 3D data collecting

They satisfy Eq.(1)

$$\begin{cases} x=SD*\cos\beta\cos\alpha \\ y=SD*\cos\beta\sin\alpha \\ z=SD*\sin\beta \end{cases} \quad (1)$$

III BP NETWORK AND GA

A. BP Network

BP network is a forward direction and no feedback network, it consists of nodes connected by net, it divides into input layer, hidden layer and output layer, as figure. 3 shows, hidden layer maybe consist of multi-layers, the neurons in every layer doesn't connect with each, signal transfers among layers.

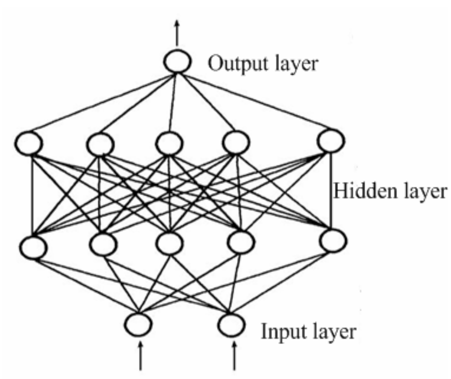


Figure.3 .Basic Model of BP Network

The network in this paper adopts single hidden layer, because firstly, the configure of multi-hidden layers is complex, and the amount of calculation is big, it will cost massive time in training process, and then Robert Hecht-Nielsen has testified that in some situation, a three-layer BP network consisting of single input, hidden and output layers can approximate a continuous function in a closed interval at a high precision [7].

The weight of network is (w_{ij}, T_{li}) , θ_i is defined as the threshold of the i^{th} neuron in hidden layer, w_{ij} is the weight of the j^{th} neuron in input layer to the i^{th} neuron in hidden layer, the energy function is defined as Eq.(2)

$$f(x) = \frac{1}{1+e^{-x}} \quad (2)$$

Supposing the serial number of training number is, input mode is $X(k) = \{x_j(k)\}$, the output of hidden layer $Y(k) = \{y_i(k)\}$, anticipant output $T(k) = \{t_l(k)\}$ and actual output $O(k) = \{O_l(k)\}$, $k = 1,2,...N$.

The output of the neuron in hidden layer $y_i(k)$ is calculated as Eq. (3)

$$\begin{cases} net_i = \sum_j w_{ij}(k)x_i(k) - \theta_i(k) \\ y_i(k)=f(net_i) \end{cases} \quad (3)$$

The output of the neuron in output layer $O_l(k)$ is calculated as Eq. (4)

$$\begin{cases} net_l = \sum_i T_{li}(k)y_i(k) - \theta_l(k) \\ O_l(k) = f(net_l) \end{cases} \quad (4)$$

The training error of the l^{th} neuron in output layer of the k^{th} sample is calculated as Eq. (5)

$$e_l(k) = \frac{1}{2}(t_l(k) - O_l(k))^2 \quad (5)$$

The holistic error of the k^{th} training sample is calculated as Eq.(6)

$$e(k) = \sum_l e_l(k) = \frac{1}{2}\sum_l (t_l(k) - O_l(k))^2 \quad (6)$$

Weight adjusting based on error feedback is the key of the network training, and the error for weight adjusting normally is two: one is the holistic error of every training sample. The other is the mean square error of all training samples.

In this paper, the holistic error of every training sample adopts $e(k)$ in Eq.(6) as the principle for weight adjusting, the general step is firstly input every sample to calculate the output through forward direction network, and then calculating $e(k)$, the weight adjusting in every layer as follows, Supposing the weight adjusting is $\Delta T_{li}, \Delta w_{ij}$, and the weight of the neuron in hidden layer to output layer

$$T_{li}(k+1) = T_{li}(k) + \eta_l \delta_l(k) y_i(k) \tag{7}$$

η_l is study efficiency, normally it belongs to (0.01, 0.9),

$$\delta_l(\mathrm{k}) = (t_l(k) - O_l(k)) \cdot O_l(k) \cdot (1 - O_l(k)) \tag{8}$$

The threshold of output

$$\theta_l(k+1) = \theta_l(k) + \eta' \delta_l(k) \tag{9}$$

η' is study efficiency of threshold, the weight of neurons in input layer to hidden layer

$$w_{ij}(k+1) = w_{ij}(k) + \eta_i \delta_i(k) x_j(k) \tag{10}$$

η_i can be the same with η_l , and the threshold

$$\delta_i(k) = y_i(k) \cdot (1 - y_i(k)) \sum_l \delta_l(k) T_{li}(k) \tag{11}$$

the threshold of hidden layer

$$\theta_i(k+1) = \theta_i(k) + \eta' \delta_i(k) \tag{12}$$

Adopting Eq.(2)~Eq.(12), studying and training network till to the performance function is smaller than ε , performance function normally is the sum error of training samples, m denotes m^{th} study, if it satisfy Eq.(13) , the network is completed

$$E^m = \sum_{k=1}^{N} \sum_l \left| t_l(k) - O_l^m(k) \right| < \varepsilon \tag{13}$$

k is the serial number of sample.

B. *Genetic Algorithm*

GA has a high capacity in finding a global optimum solution. It can fetch up the fault of BP network in getting into local optimum. Its features consist of the chromosome coding, the function of individual fitness, genetic operator and some parameters in GA. The basic flow of GA is as figure. 4 shows,

Ⅳ GA-BP NETWORK IN DATA REPAIRING

A. *repairing algorithm and the configure of network*

In section Ⅲ, the principle of collecting data from 3D laser system has been introduced, it is getting the coordinate of data in Cartesian coordinate according to *SD*, β and α , the produce of hole is because some area cannot be detected, and the *SD* will be wrong, and it will make the image anamorphic.

The wrong image has two obvious features, namely the points has the similar information nearly and α and β will not have mal position except for *SD*, the scheme of laser data repairing presented in this paper place the point cloud into a memory, and then search the area existing holes, after selecting the area around the hole as the training data for network, the GA-BP will approximate these points through incessant study, actually implementing the repairing, and then input the α and β of point in hole area to get the *SD*. The flow of GA-BP as follows.

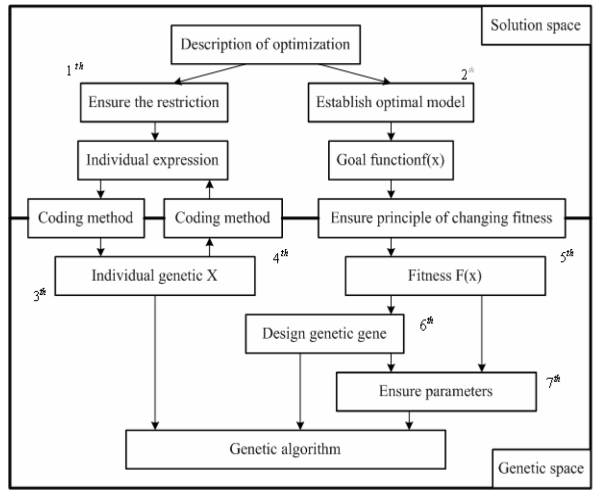


Figure.4. The flow chart of GA

1) sample normalization

$$x_i(k) = \frac{x_i(k) - x_{i\min}}{x_{i\max} - x_{i\min}} \tag{14}$$

$$y_i(k) = \frac{y_i(k) - y_{i\min}}{y_{i\max} - y_{i\min}} \quad i = 1,2 \quad k = 1,2,\ldots,N \tag{15}$$

2) ensure the allowed errors of iterative process of GA and BP ε_1 , and ε_2 , set the step length η of BP, impulse δ ,population M, variation probability λ and evolution G, the initial solution is set randomly.

3) According to choose operator and parents to implent Crossover and variation calculation.

4) Decode every chromosome, revert the configuration and weight of network, input training sample, calculate the error E of network and adaptability of order according to F.

5) Record the best chromosome, eliminate the samples with the small F, the principle of elimination is to ensure the new generated population has the same scale with before.

6) Query the error of best sample whether smaller than ε_1 or the iterative times achieving G, if no, turn to (4), otherwise continuing

7) Decode the best chromosome, query E whether smaller than ε_2 , if yes turn to (11), otherwise define the error as 为 Min_E, initialize the training times m = 0 and mean square deviation E^0 =Min_E。

8) Input the samples to calculate E^m , if $E^m < E^{m-1}$, then amend weight, make η = η *b(b is the constant bigger than 1), and turn to (10), if $E^m > E^{m-1}$, do not change weight, and then make η = η *r(r is the constant smaller than 1), and turn to(9)

9) If $E^m < \varepsilon_2$, turn to (11), otherwise change the weight according to algorithm and turn to (9).

10) End.

The configuration of network in the paper depends on the actual situation of the laser data collecting system, the configure model as figure 5 shows. In paper [9], it has proved that a neural network with three layers can approach the aim function with any precision.

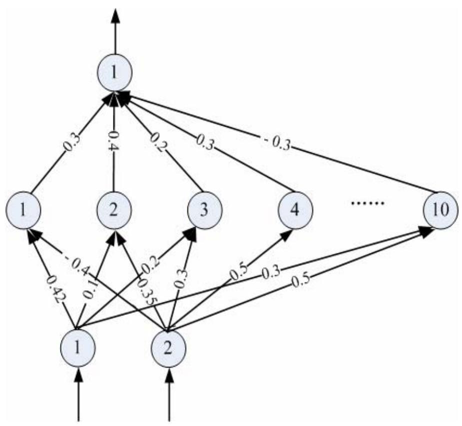


Figure. 5. The mixed coding of network

Input layer: two neurons. They denote the horizontal and pitching angle of the point, namely the α and β in Eq.1.

Hidden layer: two to ten neurons. Firstly, the number of neurons cannot be smaller than input layer, so the lower limit is 2, and then considering the hardware implement, the neurons cannot be too much, so 10 neurons is enough.

Output layer: one neuron, the output of the network is the distance from the scanning point to the lasing light emitter, so one neuron is enough.

Based on the configurable feature of BP network, the neurons of input, hidden, and output layer are all connected.

B. The parameters of GA

1) chromosome coding and population initialization

GA calculate operators on the population consisting of individuals expressed by serial code, every serial code denotes a kind of configure and combination of weight vector of network. The structure of network adopts two-value encoding, and the weight of network adopts real number encoding.

Adopting the principle upwards, to configure forward direction network, and in the process of GA, the principle of individual encoding as follows,

a) serial code adopts 10 bits binary system to express the buildup of hidden layer, for example, in figure 7, the serial code 1110000001 denotes the hidden layer consists of 1,2,3 and 10 neurons.

b) The weight of network adopts decimal fraction to express, after standardization, the decimal fraction will belong to (-1,1) . From left to right, the 30 decimal fractions denotes the 30 weights , in turn it is the weights of the first and second neurons of input layer to the first, second…tenth neurons of the hidden layer, and the first, second…tenth neurons of the hidden layer to the neuron of the output layer. As is shown in figure.6, the weight of network is 0.42，0.1，0.2，0.3，-0.4，0.35，0.3……0.3，-0.3. The serial code in GA is divided into two parts, the first part consists of ten bits binary system and the second part consists of 30 decimal fractions.

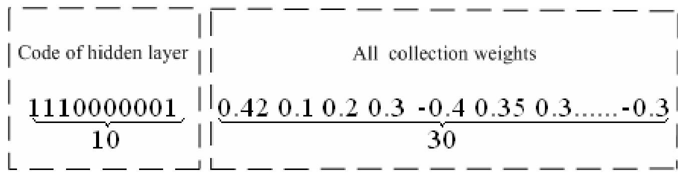


Figure.6. The serial code

In the initialization of population, selecting chromosome randomly, and then selecting the population scale M (normal 20~100), the biggest iterative times, the cross probability, and the variation probability, etc. and the initialization is finished.

2) the calculation of adaptability and selection operator of GA

The individual expressed by serial code will be changed into the configure of network through decoding, and then inputting the all training samples to calculate the error between the output of network and anticipant output, and define the reciprocal of error as the fitness of individual,

$$fitness = \frac{1}{1+\sum_{k=1}^{m} | O_l(k) - t_l(k) |} \qquad (16)$$

In Eq. (16) m is the sum of training sample, $O_l(k)$ and $t_l(k)$ are respective the actual and anticipant output of network.

This paper adopts the method of proportional fitness to decide which serial codes will be selected as the parents in the next calculation. The flow is that firstly calculating the fitness, supposing the individual fitness is $F_1 \ldots F_m$, and then calculating the sum of the fitness of every individual, $\sum_{j=1}^{m} F_j$, and define the times of the i^{th} individual copied to the next population as $COPY_i$,

$$COPY_i = \frac{F_i}{\sum_{j=1}^{m} F_j} \qquad (17)$$

Generally $COPY_i$ is decimal fraction, in the paper it will be rounded.

3) cross operator of GA

Cross operator makes GA has a high searching ability. In this paper, GA adopts mixed binary system and real number coding method, the section of binary system adopts random operator, namely generating a random number belonging to

(0,1), and then changes it into 10 bits binary system as mask code, every bit of mask corresponds to every bit of binary coding, and then referring to the bit of mask code, if the bit is 1, the binary coding of two individual will exchange the corresponding bit, for example, as figure.7 shows, A and B are parents, through exchanging to get C and D, mask code is 0000011111,

$$\left.\begin{array}{l} A{:}\ 001110\ 11010 \\ B{:}\ 110101\ 01001 \end{array}\right\} \xrightarrow{\text{cross}} \left\{\begin{array}{l} C{:}\ 001110\ 01001 \\ D{:}\ 110101\ 11010 \end{array}\right.$$

Figure.7. The cross operator

The cross calculation of real number coding doesn't affect the result of optimization, in this paper, the author adopts partly discretely crossing, namely selecting partial vectors, and then exchanging them to generate the new population, for example, elder individual are $p_1 = (u_1, u_2 ...... u_n)$ and $p_2 = (v_1, v_2 ...... v_n)$, from the bit to exchange, and the new individual after crossing as is shown below:

$$c_1 = (u_1, u_2 ... u_k, v_{k+1} ... v_n), \quad c_2 = (v_1, v_2 ... v_k, u_{k+1} .. u_n)$$

4) *variation operator of GA*

The section of binary system denotes the configure of network, the combination in solution space is little, so the setup of variation calculation can be easy, and at the same time, variation probability adopts fixed and lesser variation probability, generally to retain the comparability between new and old population and the stability of evolution, variation probability is normally selected belonged to (0.0001, 0.1).

The section of real number coding denotes the combination of weight. Variation calculation is important to the algorithm adopting real number coding, because cross calculation doesn't have a obvious affect to it, so it mainly depends on variation to get the new individual, the variation probability should be big, and the solution space is big, and of course the precision is high, here we adopt a self adaptive variation probability, the higher the fitness of individual is, the less the variation probability is, and the lower the fitness of individual is, the bigger the variation probability is, as Eq.18 shows, P_i is the variation probability of individual, size is the compositor according to the fitness of individual and P_m is the biggest variation probability.

$$P_i = P_m - \frac{[1:1:size] \times 0.01}{size} \tag{18}$$

The variation calculation of the real number section differs with the binary system, for example, $p_1 = (u_1, u_2 ...... u_n)$ is the individual vector in solution space, F_1 is its fitness and $F_{\max}$ is the biggest fitness, define variation temperature $T = 1 - \frac{F_1}{F_{\max}}$, so the heft of individual can be calculate by Eq. 19

$$u_k = \begin{cases} u_k - \Delta(T, u_k - a_k), \text{若} r\%\ 2 = 1 \\ u_k + \Delta(T, b_k - u_k), \text{若} r\%2 = 0 \end{cases} \tag{19}$$

In Eq.19, r is random signless integers, and $\Delta(T, y) = y \bullet (1 - r^{T^2})$.

V SIMULATON STUDIES

Using the GA-BP neural network to repairing the hole caused by losing data of the laser scanner is based on neural network's excellent ability for approach each swatch. Therefore the choosing of swatches is important to the performance of the data repairing.

The following experiment and simulation is based on the following Discrete Point quadratic surface:

$$Z = X^2 + Y^2 \quad X, Y \in [-4, 4] \tag{20}$$

Both variables' step of scattering is 0.1, thus X and Y are array with 40 members. Suppose, the losing data is within the 6×6 area $X \in [-1, -0.5], Y \in [1, 1.5]$. The surface which needs repairing is shown in figure. 8.

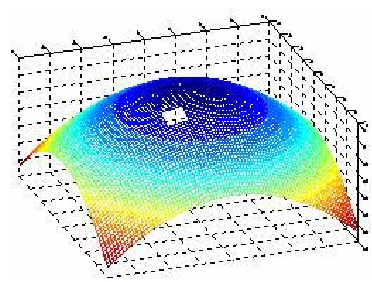


Figure.8. The surface needed repired

Choose the following three groups of swatches numbers 1,2,3.

Swatches 1: $X \in [-2.0, 0.5], Y \in [0, 3.0]$

Swatches 2: $X \in [-2.5, 1.5], Y \in [-2, 3.5]$

Swatches 3: $X, Y \in [-4, 4]$

Executing the arithmetic with each of the three kinds of swatch 10 times and make a statistic according to the following four parameters.

Training error limit: The limit of average error of the neural network's actual output according to the anticipate output of all swatch when training the neural network. The neural network can stop training when the Training error meets the limit.

Repairing error: The average error of the trained network's actual output according to the anticipate output of the losing area.

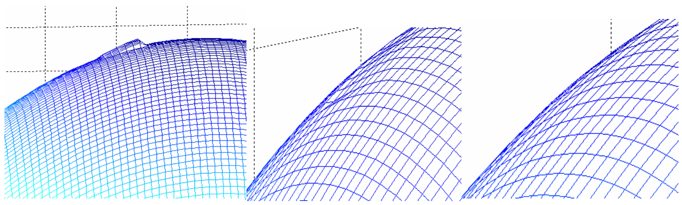
Times of training: count of the training cycles which is taken on by neural network from the starting till its meeting the Training error limit.

Time: It is the time taken on by the arithmetic's each executing.

The detail information is shown by the table 1 and the average repairing performance with each group of swatches is shown in Table 1 and figure.9.

Table 1 PERFORMANCE TATISTICS

Training error limit	Swatch group	Times of training	Repairing error	Time（second）
0.1	1	14-16	0.1786-0.3808	0.7134-0.8186
	2	21-46	0.0480-0.2817	1.6116-2.5398
	3	65-200	8.0017-8.2440	10.0659- 18.4781
0.001	1	65-182	0.0245-0.0227	2.3562-5.7419
	2	160-180	0.0062-0.0221	5.7658-12.5462
	3	178-346	7.9729-8.0087	30.0803-58.3923



(a) (b) (c)

Figure . 9. Rpairing performance of each group of swatch
a: swatch 3; b: swatch 1; c: swatch 2

The bigger the number of the swatch is the more training cycles is needed to train neural network every time and the more seconds taken by each training cycle.

The number of swatch has a very important affection to the precision of repairing. The best number of the swatch is not too many or too less. But it is much worse when there is too many swatch than too less.

The finer the Training error limit is, the more training cycle is taken by the arithmetic to meet it and much better the repairing error is.

In a word the algorithm can repairing the lost data areas well ,if the swatches are chosen suitably. The best swatches are all around the lost data areas and not too far away from them. Usually, the number of swatches is the larger , the better the arithmetic's performance is as figure.10 shows.

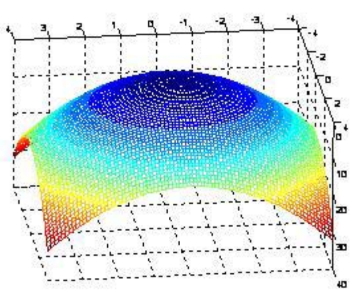


Figure . 10. Surface repaired by improved GA-BP network

CONCLUSION

In the paper, in order to repair the hole of reconstructed surface, which caused by the lost data of the laser scanner we present a method that using the neural network and data around the lost data area to do the repairing work. In face of the on line data repairing application we introduce an kind of improved BP| neural network based on GA. In this method, we optimize the structure and the weights of the BP network, as make the method more adaptive. The simulation shows that this method can not only repair the hole in an efficient way but also have a very good repairing performance. In a word, compared to the traditional method, this method can get a better performance in approaching the lost data.

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REFERENCES

[1] J. Scheffer, "Dealing with missing data," Res. Lett. Inf. Math.Sci, Mar.2002., pp.153–160

[2] Y. m. Zhong and W.C. Yang, "On Simplifying Processing of Complex Measurement Data for Making Reverse Engineering Easier," Journal of Northwestern Polytechnical University. Xi'an, vol. 4, 1997, pp.624-628

[3] P. Gu and X. Yan, " Neural network approach to the reconstruction of free form surfaces for reverse engineering," CAD, vol.27, Jan.1995 , pp.54-6

[4] B. F. David, "An introduction to simulated evolutionary optimization, " IEEE Transactions on Neural Networks, May 1994,pp.3-14

[5] K. J. Kim and S.B. Cho, "Evolving Artificial Neural Networks for DNA Microarray Analysis, " 2003

[6] B. Yang, X.H. Su and Y.D. Wang "BP neural network optimization based on an improved genetic algorithm," Proceedings of the First International conference on Machine Learning and Gybernetics. Beijing, Dec.2002, pp. 64-68

[7] M.Vittorio, "Genetic evolution of the topology and weight distribution of neural networks," IEEE Transactions on Neural Networks, May.1994,pp.39-53

[8] Z. X. Cai, J. X. Yu, X. B. Zou and Z.H. Duan "A 3-D Perceptual Method Based on Laser Scanner for Mobile Robot," IEEE International conferrence on Robotics and Biomimetics. pp.658-663

[9] R.H. Nielsen, "Theory of the back- propagation neural network," Proceedings of the International Joint Conference on Neural Networks. Washington USA, Jan. 1989,pp.593-605