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Study to the hydraulic support straightening system based on the support vector machine and chaotic particle swarm

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ABSTRACT

The reasons of hydraulic support not keeping consistency when working underground are analyzed and the influencing factors are got in the mining process. According to the input-output relationship between the influencing factors and the support displacement, we design the hydraulic support straightening system model on the basis of the support vector machines and chaos particle swarm. The model can give the accurate support displacement values for different environments through the simulation and data test, which can achieve the desired goals.

Keywords: hydraulic support straighten, support vector machines, particle swarm algorithm, chaos theory.

INTRODUCTION

The hydraulic support, which makes the work surface forward with the aid of the shearer, the scraper conveyor and other devices, is useful to protect the shearer in the coal mine underground. In the moving progress made by the hydraulic supports, the supports are difficult to keep consistency because of the unreasonable slope and cutting height which lead to the incomplete cutting of the upper and lower wall of the coal mine. Since the supports can not keep consistency, the shearer can not be protected absolutely when the top beam rises, because the front ends are of different heights. So in the work surface, manual operation helps to make the support displacements have the same displacement. Nowadays, the hydraulic support control system has been designed according to the automatic control requirements of the devices in the comprehensive mechanized mining face. However, due to the terrible environment, the data error from the data acquisition of the sensors, the automatic control of the hydraulic support control system has not been realized nowadays.

Therefore, we design a hydraulic support straighten system model. In this model, we first analyze all factors which affect the support movements, and then make the factors be considered in the support movements. In different circumstances, the system can push and pull the support in the light of the pushing force, pulling force, and the proper moving location designed by the system, which makes the hydraulic supports have the same height in the movements and cooperate with the shearer to improve the coal mining efficiency.

EXPERIMENTAL SECTION

Basic Concepts

Support Vector Machine Introduction[1-3]

The SVM (support vector machine), which is first proposed by Cortes and Vapnik in 1955, is based on the statistic studying theory, and follow the structural risk minimization. The SVM is a new technique in data mining, and can deal with the regression problems, pattern recognition and other problems.

The basic idea of the SVM is to map the vectors to the high dimensional feature space, denoted by Ω, through the nonlinear mapping. And in Ω, the linear regression can be finished in this feature space by constructing the optimal hyperplane.

$$f(x) = (w \bullet \varphi(x)) + b \tag{1}$$

where $(\bullet)$ presents the transvection in Ω, and $\varphi: x \to \Omega$. b is the threshold, and is the non-linear regression of the corresponding low dimensional input space, expressed by R^n, which is the counterpart of the linear regression in the high dimensional space Ω.

Give l learning samples of independent distribution, the set of which is $T = \{(x_1, y_1), (x_2, y_2), \cdots (x_l, y_l)\} \in (X \times Y)^l$, where $x_l \in X \in R^n$, $y_l \in R^n$, $y_l \in Y \in R$, $i = 1, 2, \cdots, l$. Then construct the regression hyperplane. And the corresponding optimal question of the regression hyperplane can be written as follows:

$$\min_{w,b,\xi^*} \frac{1}{2}\|w\|^2 + C\sum_{1}^{l}(\xi_i + \xi_i^*) \tag{2}$$

$$\text{s.t.} \quad (w \bullet \varphi(x)) + b - y_i \le \varepsilon + \xi_i, i = 1, 2, \cdots, l, \tag{3}$$

$$y_i - (w \bullet \varphi(x)) - b \le \varepsilon + \xi_i^*, i = 1, 2, \cdots, l, \tag{4}$$

$$\xi_i, \xi_i^* \ge 0, i = 1, 2, \cdots, l$$

where $\xi^{(*)} = (\xi_1, \xi_1^*, \cdots \xi_l, \xi_l^*)$ are non-negative slack variables. $\varepsilon > 0$ is the parameter of the insensitive loss function, and C is the penalty parameter. Here, we introduce Lagrange multiplicator to construct the function. Then the dual problem of the original problem is

$$\max_{w,b,\xi^{(*)}} \sum_{i=1}^{l} y_i(a_i^* - a_i) - \frac{1}{2}\sum_{i,j=1}^{l}(a_i^* - a_i)(a_j^* - a_j) \bullet K(x_i, x_j) - \varepsilon\sum_{i=1}^{l}(a_i^* + a_i) \tag{5}$$

s.t.

$$\sum_{i=1}^{l} (a_i^* - a_i) = 0, 0 \le a, a_i^* \le C, i = 1, 2, \cdots, l$$

so, the required optimal regression hyperplane can be expressed as

$$f(x) = (w \bullet \varphi(x)) + b = \sum_{i=1}^{n_{sv}}(a_i^* - a_i)(\varphi(x_i) \bullet \varphi(x)) + b = \sum_{i=1}^{n_{sv}}(a_i^* - a_i)K(x_i, x) + b, \tag{6}$$

where n_{sv} is the number of the support vectors, and $K(x_i, x) = \varphi(x_i) \bullet \varphi(x)$ is the core function, which is $K(x_i, x)$, meeting the Mercer conditions. The replacement of the core function with the transvection in high dimensional space avoids the complex point operation. The common core functions include polynomials, RBF core, Fourier core, B sample core, etc. In this paper, we use the RBF core.

Chaotic Particle Swarm Algorithm Introduction

Chaos Theory

Chaos, which is stochastic, regular and popular, is a comparatively prevalent phenomenon in the nature, and can step all status following its laws in a certain range. The basic idea of the chaos theory is as follows. Firstly, introduce the chaos state into the optimal variables, and then enlarge the ergodic scope of the chaotic motion to the scope of optimal variables. Next, variable code and genetic operation are done by chaotic map. Secondly, attach small disturbances to the chaotic variables, and then converge on a most proper individual through iteration. So the optimal solution can be got. The common chaotic methods are introduced as bellow.

(1) One-dimensional Logistic map. That is

$$X_{n+1} = \mu X_n (1 - X_n) \tag{7}$$

where $X_n \in (0,1)$. When $\mu = 4$, the variable range is chaotic completely.

(2) Two-dimensional Henon discrete mapping. That is

$$x_{n+1} = 1 - \alpha x_n^2 + \beta y_n \tag{8}$$

$$y_{n+1} = x_n \tag{9}$$

where when $1.07 \le \alpha \le 1.097$ and $\beta = 0.3$, the variable range is chaotic completely.

Particle swarm algorithm

Particle swarm algorithm is based on the predatory behaviors of birds. This method compares the birds to particles. When the solution set of the problems is generated in the random research of particles, the particles can find the best positions of themselves and the group. In this process, the group can finish the search in the solution space. Different from other intelligent algorithms, in the particle algorithm, each particle, which is like a bird, has memory function and can preserve the memory of the optimal solution. Similarly, the group can also keep the memory of its optimal solution. According to the group intelligent algorithm, the particle swarm algorithm, which is one of the most effective methods, is proposed by Dr. Kennedy and Pro. Eberhart in 90s, 20C[4,5].

The procedure of the particle swarm algorithm is as follows.

(1) Initialization. We set c_1 and c_2 are two accelerative constants and $T_{\max}$ is the maximal evolution number. First we set the current evolution number, which is denoted by t is 1, and that is $t = 1$. Then in the space R^n, we get m randomly generated particles, presented by $x_1, x_2, ...x_m$, which builds the initial group $X(t)$. Secondly, we generate the initial displacement variation of each particle randomly, which establishes the displacement variation matrix $V(t)$.

(2) Group $X(t)$ evaluation. Calculate the fitness of each particle.

(3)Choose the better one between the optimal $pbest$ of the particle itself and the fitness through comparison. If the current value is better, we choose the current one. At the same time, let $pbest$ be the current position in the $n-$dimensional space.

(4)Find the better one between the particle fitness and the group optimal. If the current one is better, take $pbest$ as the subscript and the fitness of the current particle.

(5)Follow the Eq.(10) and Eq.(11) to update the next detections and steps of particles, and then we get the new group $X(t+1)$.

$$v_{id}^{(i+1)} = v_{id}^{(i)} + c_1 r_1 (p_{id}^i - x_{id}^i) + c_2 r_2 (p_{id}^i - x_{id}^i) \tag{10}$$

$$x_{id}^{(t+1)} = x_{id}^{(t)} + v_{id}^{(t+1)} \tag{11}$$

(6)Return to the termination conditions. If the end condition is qualified, the search ends, otherwise, $t = t + 1$, and return to step (2). When the iteration generation reaches the maximum evolution generation $T_{\max}$, the search ends.

Hydraulic Support Straightening System Design

Support System Analysis

In the stope face, in order to protect the security of machines and people, we have to support and manage the roof to prevent the roof slip of the work face. The hydraulic support is one of the support equipment in the stope face. In the process of the support motions, the supports in a row appear to move not synchronously for some reasons, which may affect the shearer work. So in this paper, we first find all factors affecting the synchronous movements of the shearer, and take these factors as the input variables of the support straightening system. Then we take the pushing force and pulling force between the support and the scraper conveyor as the output variables. In this section, we will take the shield support ZY3200/12/32 for example to analyze and design.

After analysis, we can determine the influencing factors above including support quality(SQ), support height(SH), hub distance(HD), setting load(SL), support movement with or without pressure(SM), carrying bar length(CBL), base width(BW), the distance from the carrying bar to the shearer(DFCBS), the distance from the beam end of the support to the wall of the coal mine(DFBEWCM), adaptive tilt(AT), the thickness of coal seam(TCS), shielding strength(SS), working resistance(WR),support movement force(SMF), pushing force(PF) ,support displacement(SD)and so on. Since the support quality, hub distance and some other factors will not change in the design for the supports of the same type, these factors are not regarded as the main factors. For each affecting factor, the value range is set as bellow.

Support height: 1.3~3.2m;
Setting load: 1911~1898kN;
Working resistance: 2813~2940kN;
Shielding strength: 0.568~0.598MPa;
Adaptive tilt: $\leq 35^{o}$;
Pushing force: 100~150 kN;
Carrying bar length: 1.5~2.5m;
Base width: 1.1~1.2m;
Support displacement:600~700mm;
The distance from the carrying bar to the shearer: 150~250mm;
The distance from the beam end of the support to the wall of the coal mine: 200~400mm.

The values above are the basis of the design of support strengthening system.

Modeling Support Straightening System

Design Steps of the Support Straightening System

On the basis of the reason analysis of the hydraulic supports not keeping consistency when working, we design the hydraulic support straightening system by combing the reasons and the support vector regression machine-the particle swarm algorithm-chaos theory. The design steps are introduced in detail as bellow.

(1)Data collection. Analyze the reason why the hydraulic support can not move consistently, and build input-output relationship of the straightening system .
(2)Data preprocessing. Collect the reasonable data and formalize the data in the light of the input-output relationship. That means converting the different ranges of various data into a uniform range. For example, into $[a,b]$, where a and b are integers.
(3)Classify the processed data into the training set and the test set by using the sampling technique. That is taking the several groups of the formalized data randomly as the test set, and the others form the training set.
(4)Combine the support vector regression machine, the particle swarm algorithm and the chaos theory to model the straightening system. In this paper, we use the radial basis function (RBF) as the core function in the support vector regression machine. At the same time, we initialize the particle positions with the SVM, and find two best parameters of the penalty function and the core function in the support vector regression machine by using the particle swarm algorithm. Then put the parameters in the program of the support vector regression machine, and get the model of the hydraulic support straightening system.
(5)After training the model, verify the trained model with the data in the test set. And then verify the model with the data of the training set again.
(6)Evaluate and analyze the results, and finish the system design.

The Data Obtainment of the System Design

The support system design take the moving support force and the pushing force as the output values of the system design, and the eight factors mentioned above as the input values. In the range of the influencing factors in 2.2.1, generate 60 groups of data randomly, where 50 groups form the training set, and the other 10 groups form the test set. Due to the fact that the data is generated randomly and the data is in the proper range, the data presents certain conditions likely to happen in the real environment. We show he data generated in Table 1.

Table 1 The input-output data in the hydraulic support straightening system

	Input								Output	
	SH	SL	WR	SS	DFCBS	DFBEWCM	SD	AT	SMF	PF
1	1.3	1911	2813	0.568	150	200	600	0	150	100
2	1.33	1910.94	2815	0.5685	151	203	601	1.4	152	100.5
3	1.37	1910.88	2818	0.569	153	206	603	1.7	154	101.7
4	1.41	1910.25	2820	0.5695	155	210	605	1.9	156	102.7
5	1.46	1909.96	2822	0.57	157	214	608	2	159	103.6
6	1.5	1909.86	2823	0.5705	160	217	610	2.3	163	104.3
7	1.53	1909.43	2825	0.571	162	220	611	2.8	166	105.2
8	1.58	1909.11	2827	0.5715	161	223	612	3	168	105.9
9	1.61	1908.87	2830	0.572	163	225	614	3.4	170	106.7
10	1.65	1908.59	2833	0.5725	165	229	617	3.6	173	107.8
11	1.7	1908.46	2836	0.573	166	233	619	4	175	108.1
12	1.78	1908.23	2838	0.5735	168	237	621	4.1	177	109.4
13	1.82	1907.95	2841	0.574	170	240	623	4.3	179	110
14	1.86	1907.69	2843	0.5745	172	243	624	4.5	180	110.5
15	1.91	1907.32	2845	0.575	174	246	625	4.9	182	101.3
16	1.94	1907.06	2848	0.5755	175	249	627	5	185	102.7
17	1.98	1906.91	2850	0.576	177	251	629	5.2	187	103
18	2.03	1906.77	2851	0.5765	180	255	631	5.8	190	103.8
19	2.07	1906.24	2853	0.577	182	257	633	6.1	193	104.5
20	2.13	1905.99	2855	0.5775	185	260	634	6.7	194	105.6
21	2.19	1905.83	2858	0.578	189	263	634	7	195	106.3
22	2.24	1905.65	2861	0.5785	191	265	636	7.3	197	107
23	2.26	1905.25	2864	0.579	193	268	638	7.5	199	107.9
24	2.31	1904.93	2867	0.5795	195	271	640	7.7	203	108.8
25	2.33	1904.68	2870	0.58	198	274	642	7.9	205	109.4
26	2.37	1904.38	2872	0.5805	201	277	645	8	207	110.6
27	2.41	1904.01	2874	0.581	204	280	647	8.3	209	111
28	2.45	1903.88	2876	0.5815	105	281	648	8.8	211	111.7
29	2.49	1903.54	2878	0.582	207	283	650	9	213	112.6
30	2.54	1903.27	2881	0.5825	208	287	651	9.3	215	113.5
31	2.59	1902.89	2884	0.583	210	290	652	9.7	217	114.3
32	2.62	1902.67	2887	0.5835	211	293	654	10	220	114.9
33	2.63	1902.31	2890	0.584	213	296	657	10.2	222	115.8
34	2.64	1901.98	2892	0.585	215	299	659	10.7	223	116.7
35	2.67	1901.76	2895	0.586	217	302	661	11	224	117.4
36	2.7	1901.42	2897	0.5865	219	305	664	11.6	227	118.6
37	2.73	1901.13	2900	0.587	220	307	668	11.9	230	119.1
38	2.76	1900.12	2902	0.5875	223	310	670	12.2	233	120.4
39	2.77	1899.97	2904	0.588	225	314	672	12.4	235	121.4
40	2.8	1899.88	2906	0.5885	226	319	673	12.8	237	123.1
41	2.82	1899.79	2908	0.589	227	321	675	13	238	124
42	2.85	1899.63	2911	0.5895	228	324	677	13.4	240	125
43	2.87	1899.51	2913	0.59	229	326	679	13.8	241	125.7
44	2.9	1899.4	2914	0.5905	231	330	681	14.3	245	126.6
45	2.93	1899.34	2915	0.591	232	334	683	14.6	247	127.8
46	2.95	1899.27	2918	0.5915	234	338	684	15.2	250	129.4
47	2.97	1899.12	2920	0.592	236	342	686	15.7	255	130
48	3	1898.99	2921	0.5925	238	347	688	16	258	131.7
49	3.03	1898.91	2923	0.593	239	350	689	16.4	261	132.5
50	3.06	1898.82	2925	0.5935	240	353	690	16.8	265	134.3
51	3.09	1898.76	2927	0.594	241	356	691	17.1	269	135.8
52	3.11	1898.58	2929	0.5945	243	359	692	17.7	273	136.8
53	3.12	1898.44	2930	0.595	245	362	693	18	275	138.2
54	3.13	1898.36	2931	0.5955	246	368	692	18.3	281	140.5
55	3.15	1898.21	2932	0.596	247	371	695	18.8	284	142.6
56	3.16	1898.19	2934	0.5963	247	374	696	19	286	143.7
57	3.17	1898.16	2935	0.5968	248	376	697	19.2	289	144.9
58	3.18	1898.12	2937	0.597	248	380	698	19.5	291	146.9
59	3.19	1898.08	2938	0.5975	249	385	699	19.8	296	148.8
60	3.2	1898	2940	0.598	250	400	700	20	300	150

The Formalization of Sampling Data

Because the differences among the data values are big, and some even reach the order of magnitude with different measurement units as well, we have to formalize the data before preprocessing the data. Since each data we use is integer, if the processed data appears negative, the subsequent steps stop. Therefore, the set range after the normalization is[1,2]. Furthermore, the formalization is finished by using the function transition method.

We select 50 groups from the formalized data as the data of the training set, and the data is trained by the program. Then the remaining 10 data groups are in the test set, the data of which is used to test the trained model. The initial data of the 50 groups in the training set and the initial data of the 10 groups in the test set are shown in Figure 1.

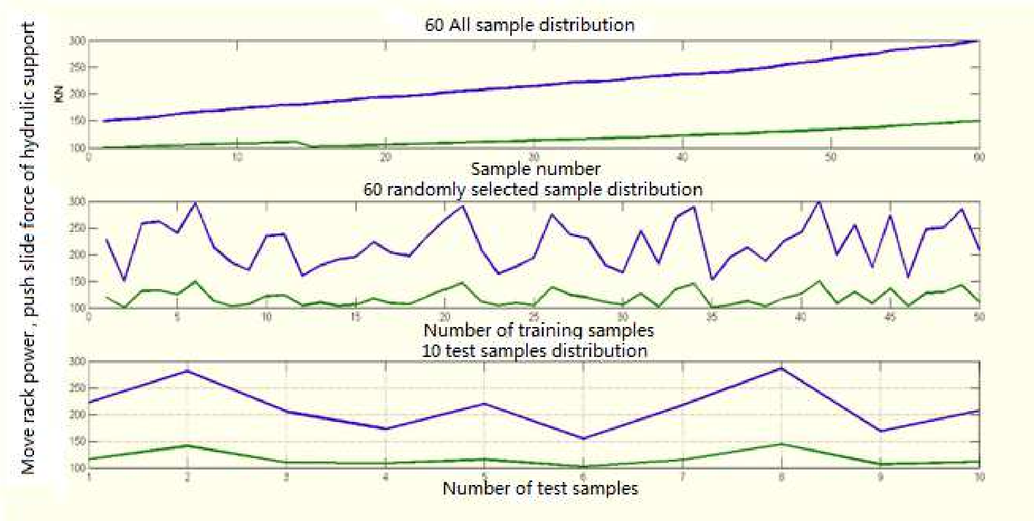

Figure 1 Original data distribution

The formalized data of the 60 groups, the data of the 50 groups in the training set and the data of the 10 groups in the test set are shown in Figure 2.

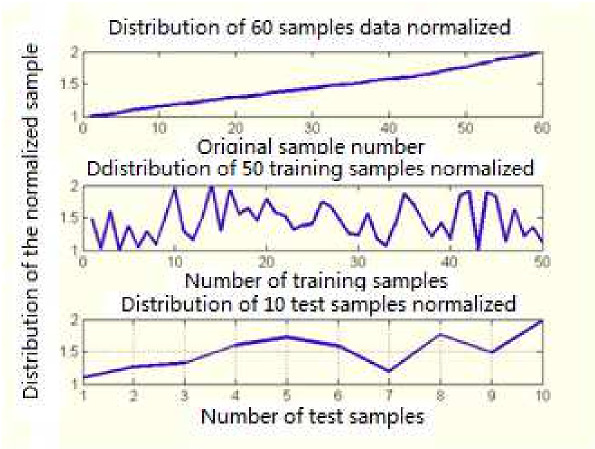

Figure 2 Normalized data distribution

The input data includes 8 columns, and output data occupies 2 columns. Converting the training data and the test data into the Matlab format, the file name is data.mat for later use.

The Particle Swarm Algorithm

Program the particle swarm algorithm to determine the penalty parameter 'c' and the smoothing factor 'g'. By running the program, the evolution of the particle swarm algorithm is exhibited in Figure 3 (the group number is 20, and the evolution number is 200). Then we train the model by putting the best 'c' and 'g' in the support vector regression machine.

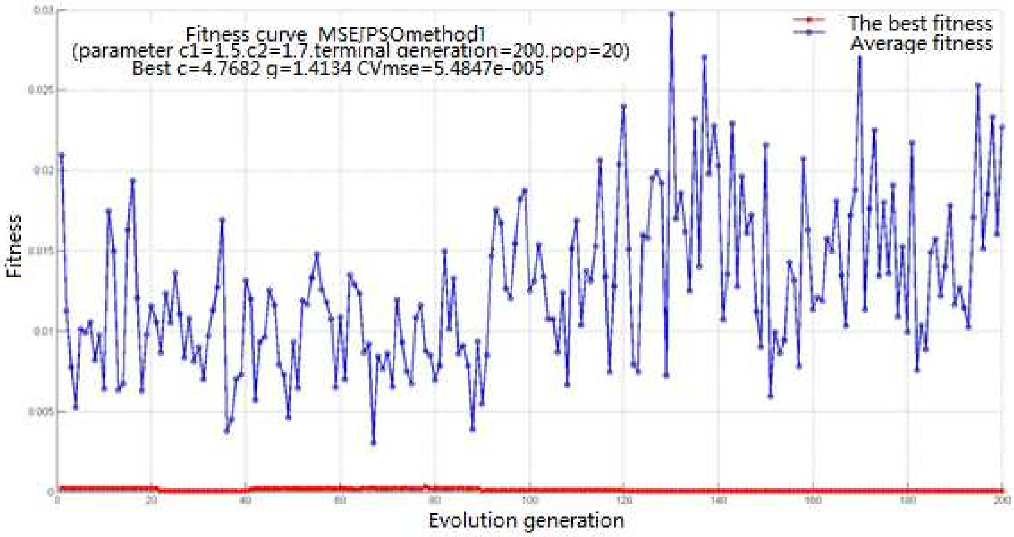

Figure 3 The evolution process of the particle swarm algorithm

Program the SVM

Here the SVM kit we use is the 'libsvm-3.1-[Faruto]', and we choose the RBF to program the input-output relationship in the hydraulic support straightening system. And the training begins when we put the best 'c'and'g'in the program of the support vector machine. After training the model, the data in the training and test sets is put in the system to test the model. The test results are as follows.

(1)Put the test data in the model to make a test, and make a comparison between the results and the output values of the initial data. The error distribution is shown in Figure 4.

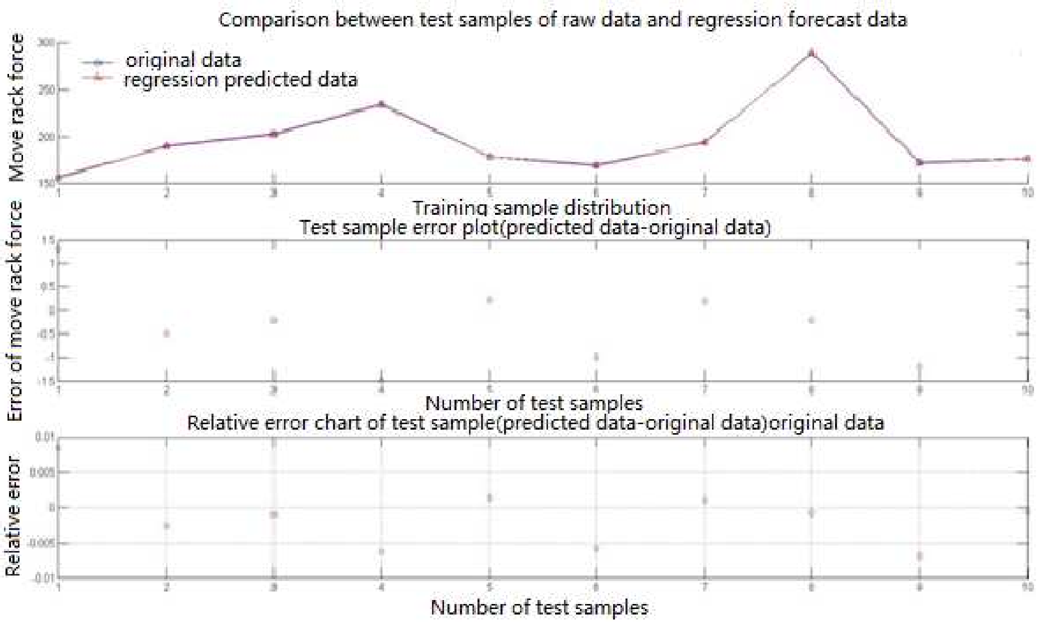

Figure 4 The error distribution of test results and the output values of original data

(2)Put the training data in the model to make a test, and make a comparison between the results and the input values of the initial data. The error distribution is given in Figure 5.

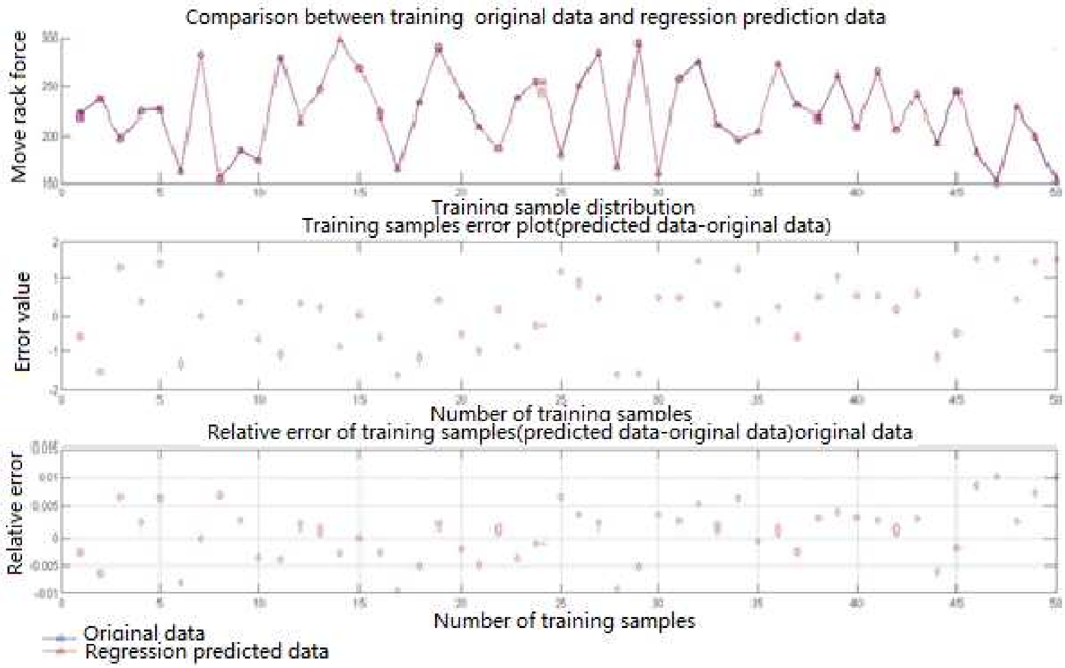

Figure 5 The error distribution of training results and the input values of original data

RESULTS AND DISCUSSION

Model Test and Results Analysis

In the training, the group number of the particles is 20, and the training iteration termination generation is 200. We get the best 'c' and 'g', where c=61.5033, and g=0.18044. Then we take the best 'c' and 'g' to the program of the support vector regression machine, and make a test using the data in the test set and training set. After that, we analyze the error according to the test results.

(1)data of the test set test
From the test results, we can see that the absolute error of the moving support force is in [-1.5Kn,1.5kN], but the relative error is in [-0.01,0.01]. Compared with the range of the moving support force, the relative error is very slight.

(2)data of the training set test
The training results are based on the input-output relationship of the data in the training set. When the training finishes, we take the data in the training set in the program to test. Then the results show that the absolute error of the moving support force is also in [-2Kn,2kN], and the relative error is in[-0.01,0.01]. Compared with the range of the moving support force, the relative error is very slight as well.

CONCLUSION

In this paper, we analyze the reason why the hydraulic support can not keep consistency in the movement, and find 8 influencing factors. At the same time, we build the input-output relationship between the moving support force and the pushing force, both of which have business with the support movement. Then we determine ranges of the input-output parameters in the support movement and generate a series of data in the ranges. In addition, we model the relationship using the support vector regression machine and the chaotic particle swarm algorithm, and make the training. Then the model is established after the training. After we analyze the error of the output results though testing the input data, the experiment results show that the model can achieve the anticipate purposes.

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