

Research on Performance Quality Prediction Method of Missile Based on Grey Theory and SVM

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Abstract—Accurately grasping the performance quality status of the missile is a prerequisite for ensuring the completion of the operational task. At present, in a real missile launch exercise, in order to ensure the success of the launch, the method of first passing the test and then launching is usually adopted. This method can hardly meet the large-scale, high-volume and high-efficiency operational requirements in the future battlefield. In order to meet the future operational requirements, based on the past test data of the performance parameters of the missile and the information of daily management and stored, combined the information of actual missile launch results, this paper uses grey theory, linear weighted comprehensive evaluation and SVM to accurately predict the performance quality status of the missile, and provide technical support for operational decision-making.

Keywords—grey theory; linear weighted; SVM; quality prediction

I. INTRODUCTION

The effect of the missile mainly depends on the status of its own performance and quality, and the performance quality of the missile is accurately mastered, which plays an important role in the operation and management decision of the army. At present, in the real missile launching rehearsal, the launching missile is tested first, and the launch is carried out after the test confirms that the performance quality of the missile is qualified. Because the missile is a multilevel complex weapon system, the data parameters are numerous and the test time consuming and energy consuming, which takes up a lot of time during the whole practice. However, in the future joint operations, the missile forces are inevitably faced with large-scale and efficient operations. If we still use the mode of launching after testing the missile first, we will surely bungle the chance of winning a battle. Therefore, accurate prediction of the missile's performance quality status is the inevitable requirement for the missile troops, and is also of great significance for the future joint operations.

This paper, based on the test data of missile performance parameters and daily management and storage information, combined with the result information of live launch, uses grey theory, linear weighted comprehensive evaluation and support vector machine to predict the performance quality status of missile performance parameters, subsystems and whole missile system in turn. It provides a way for prediction of missile performance quality status.

II. PREDICTION IDEAS

First, the grey prediction has the advantages of few samples, simple calculation and high precision of short-term prediction. The effect is better for small data samples and single step prediction [1,2]. Although the data amount of the whole missile is very large, the amount of data to a single parameter is still very small. Therefore, we can use grey theory to predict the parameters data of missile based on the information collected in the past.

Secondly, the linear weighted comprehensive evaluation method has the advantages of easy calculation, easy to apply and popularize. It can evaluate the performance quality status of subsystems of the missile by the method of linear weighted comprehensive evaluation according to the prediction results of the parameters and the daily management and storage information.

Finally, the support vector machine (SVM) has a mature theoretical basis, and its generalization performance is very good. It has strong advantages in dealing with the nonlinear high dimensional number and local minima of small sample data, and can be extended to other machine learning problems, such as function fitting [3]. The support vector mechanism can be used to build a model to establish the relationship between the missile launching result information and the performance quality status of subsystems, so as to realize the reliable prediction of the performance quality status of the missile to be launched.

The prediction process of the performance quality status of the missile is shown in Figure 1.

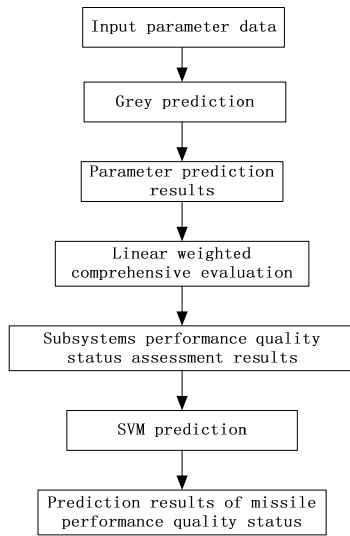


FIGURE I. FLOW CHART OF MISSILE PERFORMANCE QUALITY STATUS PREDICTION

III. PREDICTION OF MISSILE PERFORMANCE PARAMETERS BASED ON GREY THEORY

Taking the performance parameter A of a missile warhead as an example, the GM (1,1) prediction model is selected for 3 years' prediction (test data of parameter A refer to table 1).

TABLE I. WARHEAD-PARAMETER A TEST DATA COLLECTION

Parameter A test data		
measured value	test times	□□□□□□□□□□
0.084	1	1
0.085	2	2
0.084	3	3
0.083	4	4
0.084	5	5

A. Prediction Process

a. Suppose $X^{(0)}$ is a sequence of non negative raw data, $X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n)\}$, where $x^{(0)}(i)$ corresponds to the output of the system at the time.

$$X^{(0)} = (0.084, 0.085, 0.084, 0.083, 0.084)$$

b. A grey cumulative for $X^{(0)}$ is used to get a new generated data sequence $X^{(1)}$.

$$X^{(1)} = (0.084, 0.169, 0.253, 0.336, 0.420)$$

c. The grey model GM (1,1) is established from the new data sequence $X^{(1)}$, and the corresponding albino differential equation is

$$\frac{dx^{(1)}(t)}{dt} + ax^{(1)}(t) = b$$

Grey differential equation is:

$$x^{(0)}(k) + az^{(1)}(k) = b$$

Among them, a is the development coefficient, b is the grey function, and $z^{(1)}(k)$ is the background value of $x^{(1)}(k)$ on $[k-1, k]$.

$$Z^{(1)} = (-0.1265, -0.2110, -0.2945, -0.3780)$$

d. The least squares method is used to estimate parameters a and b, and the parameter $\hat{\alpha} = \begin{pmatrix} \hat{a} \\ \hat{b} \end{pmatrix}^T$ is:

$$\hat{\alpha} = \begin{pmatrix} \hat{a} \\ \hat{b} \end{pmatrix}^T = (B^T B)^{-1} B^T Y = (0.004785, 0.085208)^T$$

$$\text{Among them, } B = \begin{bmatrix} -1.4315 & 1.0000 \\ -0.2110 & 1.0000 \\ -0.2945 & 1.0000 \\ -0.3780 & 1.0000 \end{bmatrix}, Y = \begin{bmatrix} 0.085 \\ 0.084 \\ 0.083 \\ 0.084 \end{bmatrix}$$

e. The time response function of the differentiation of the whitening equation is

$$\hat{x}^{(1)}(t) = \left[x^{(1)}(1) - \frac{b}{a} \right] e^{-a(t-1)} + \frac{b}{a}$$

It is discretized into a time response sequence

$$x^{(1)}(k) = \sum_{i=1}^k x^{(0)}(i), k \in (1, 2, \dots, n)$$

$$\hat{X}^{(1)} = [0.0840, 0.1686, 0.2528, 0.3366, 0.4200]$$

f. $\hat{X}^{(1)}$ is a modeling prediction sequence based on $x^{(0)}(k) = x^{(1)}(k) - x^{(0)}(k-1), 2 \leq k \leq n$. A reduction of $\hat{X}^{(1)}$ is used to get the fitting value of raw data $\hat{X}^{(0)}$.

$$\hat{X}^{(0)} = [0.0840, 0.0846, 0.0842, 0.0838, 0.0834, 0.0830, 0.0826, 0.0822]$$

B. Prediction Results

We compare the raw data and predicted data of parameter A, as shown in Table 2.

TABLE II. WARHEAD-PARAMETER A DATA PREDICTION COMPARISON

	first year	second year	third year	fourth year	fifth year	first year of prediction	second year of prediction	third year of prediction
raw data	0.084	0.085	0.084	0.083	0.084			
prediction data	0.0840	0.0846	0.0842	0.0838	0.0834	0.0830	0.0826	0.0822
residual	0.0000	-0.0004	0.0002	0.0008	-0.0006			

IV. QUALITY STATUS ASSESSMENT OF SUBSYSTEMS BASED ON LINEAR WEIGHTED COMPREHENSIVE EVALUATION

The performance quality assessment of the missile subsystems depends not only on the performance parameters, but also in the comprehensive consideration of the service resume and appearance information, which are mainly derived from the daily management and storage. Taking a missile warhead as an example, the evaluation system of warhead performance quality status is established, as shown in Figure 2. The linear weighted comprehensive evaluation method is applied to evaluate its performance and quality.

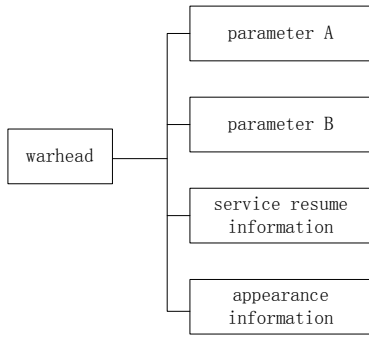


FIGURE II. WARHEAD EVALUATION INDEX SYSTEM

Select a set of data from the previous test data:

$$X = (x_1, x_2, x_3, x_4)^T = (0.7000, 0.9142, 0.9933, 0.9672)^T$$

The weight coefficients corresponding to the parameters of each parameter are:

$$W = (w_1, w_2, w_3, w_4) = (0.2632, 0.4500, 0.0752, 0.2116)$$

Using linear function

$$y = F(W, X) = \sum_{i=1}^m w_i x_i$$

By calculation, $y=0.8750$.

Among them: y represents the joint evaluation value, x_i ($i=1, 2, \dots, m$) is the evaluation value of each

Similarly, grey prediction can be used to predict other performance parameters of the missile.

evaluation index data, and w_i ($i=1, 2, \dots, m$) is the weight coefficient of each evaluation index parameter ($0 \leq w_i \leq 1, \sum_{i=1}^m w_i = 1$).

In the same way, on the basis of the parameters of the grey prediction, combined with the daily management and storage information, the evaluation value of the performance quality of other subsystems can be obtained by using the linear weighted comprehensive evaluation method.

V. PREDICTION OF PERFORMANCE QUALITY STATUS OF THE WHOLE MISSILE SYSTEM BASED ON SVM

A. Prediction Ideas of SVM

First, we establish a one-to-one correspondence between the hitting effect of missile such as the landing point CEP and the quality level of the whole missile system. According to the results of the live launching, the whole missile system is divided into excellent, good, general and unqualified, and it is used as the output of SVM. Performance quality status evaluation of subsystems before launch is used as input of SVM. The input and output of a one-to-one corresponding support vector machine are established on the basis of the information before and after missiles' live launching. Then we use the sample data to train the support vector machine to determine the penalty factor and kernel function. Finally, the performance quality assessment results of subsystems of the missile to be launched are put into the established support vector machine prediction model to predict the performance quality status of the whole missile system

B. SVM Modeling

When using SVM modeling, the training sample is mapped to a high dimensional space by inner product kernel function. In this high dimensional space, the maximum classification hyperplane is established. SVM improves its generalization ability by searching the least risk structure to improve its generalization ability[4]. The mapping of nonlinear data to high dimensional space is shown in Figure 3. Generally speaking, the essence of SVM is the two class classification problem, which can be regarded as a linear classifier to find the maximum classification interval in a feature space, which maximizes the classification interval.

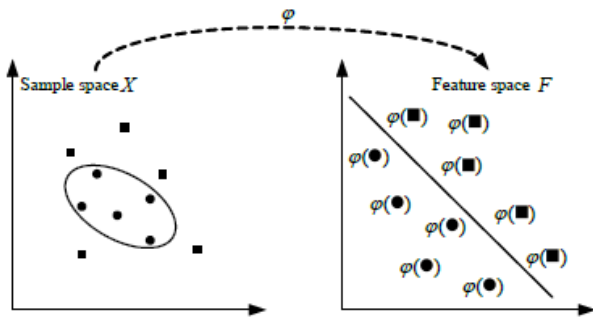


FIGURE III. MAPPING NONLINEAR DATA TO HIGH DIMENSIONAL SPATIAL SCHEMATIC DIAGRAM

In support vector machines, the main parameters that mainly affect their learning efficiency and generalization ability are the value of the penalty factor c and the kernel function parameter g , but the support vector machine does not provide a simple method to select the two parameters well. In the practical application, chaos optimization, genetic algorithm and grid search are generally used to search for the optimal parameter of support vector machines[5]. The chaotic optimization and genetic algorithms are applicable to the processing of large sample data, but the optimal parameters are uncertain, and the optimal parameters can not be obtained. The grid search method can search all the parameters within the specified range, and can determine the optimal parameters, so it is suitable for the processing of small sample data, but the prediction rate is slow. For missile such special equipment, the number of firing rounds is not very large, and the available samples are relatively few. Therefore, grid search method is adopted here.

The basic principle of grid search method is to find all the required parameter combinations in a given rectangular range

according to the given step size. The specific steps are as follows[6]:

Step 1: The values of c and g in grid search are set in a reasonable range and the corresponding step length is determined. At this point, a two-dimensional grid is constructed on the coordinate system of c and g .

Step 2: A pair of parameters (c , g) is extracted from the constructed coordinate system, and the training samples are trained by LIBSVM software, then the test sample is used to predict the support vector machine, and the accuracy rate is recorded.

Step 3: Repeat Step 2 until all parameter combinations in the two-dimensional mesh are trained once.

Step 4: Finally, all parameters are represented by contour lines (c , g), and the best values of c and g are determined.

When using SVM to predict the performance quality of a certain type of missile, 15 input nodes, that is, the performance quality assessment value of 15 subsystems, and 4 output nodes, are "1,2,3,4", representing "excellent, good, general and unqualified".

C. Performance Quality Status Prediction

Using 26 launched missiles in Table 3 as learning samples, the missile performance quality status prediction model is constructed by LIBSVM software. In Table 4, 4 launched missiles are tested samples. The penalty factor c and kernel function parameter g obtained by grid search method and its contour lines are shown in Figure 4. $c=0.00097656$, $g=64$ can be seen from the diagram. The recognition rate is 100%.

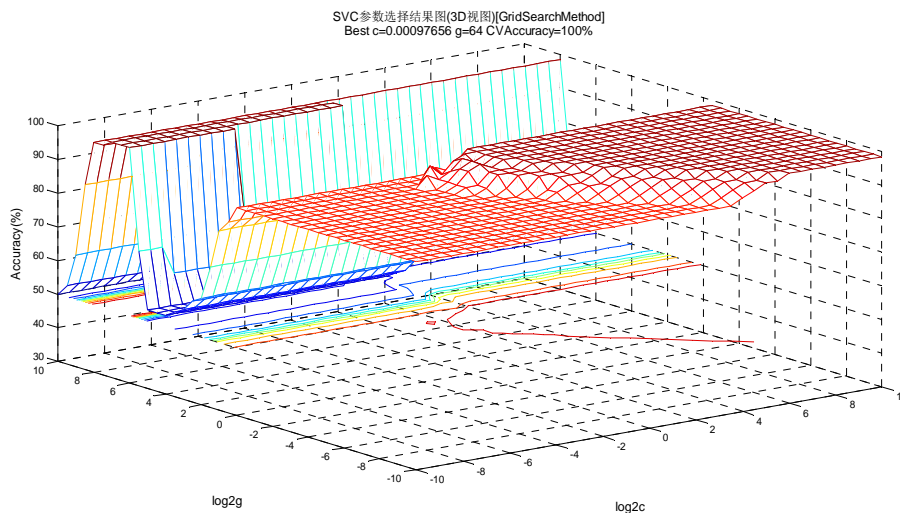


FIGURE IV. THE CONTOUR MAP OF THE PARAMETER PAIR (C , G)

TABLE III. PERFORMANCE QUALITY STATUS EVALUATION OF 26 MISSILES LAUNCHED BY A DEPARTMENT

number	status level	the whole missile system	I ₁	I ₂	I ₃	I ₄	I ₅	I ₆	I ₇	I ₈	I ₉	I ₁₀	I ₁₁	I ₁₂	I ₁₃	I ₁₄	I ₁₅
1	excellent	09161	09374	09305	07343	07465	09110	09143	09247	09343	09273	09254	07597	09308	08311	08729	09686
2	excellent	09151	09667	09029	08352	07465	08979	09317	09339	09167	09296	09356	07597	09440	08495	08840	09719
3	excellent	09191	09391	09305	07843	07463	08976	09318	09343	09369	09262	09350	07597	09286	08463	08658	09543
4	excellent	09103	09517	09032	08475	07465	08990	09175	09257	09316	09288	09272	07597	09160	08467	08698	09619
5	excellent	09214	09457	09391	07822	07465	08898	09207	09352	09313	09271	09353	07597	09349	08189	08678	09235
6	excellent	09103	09591	09006	07831	07465	09169	09304	09360	09330	09275	09254	07597	09416	08290	08755	09737
7	good	09041	09667	08921	07460	07463	09166	09305	09341	09299	09249	09350	07597	09303	08514	08587	09468
8	good	09058	09667	08973	07555	07465	08742	09281	09349	09381	09254	09351	07597	09109	08450	08698	09423
9	good	09097	09245	09305	06275	07465	08382	09306	09356	09380	09284	09265	07597	09298	08440	08750	09695
10	good	09073	09386	09029	07138	07872	08948	09415	09454	09227	09288	09437	08150	09320	08367	08891	09767
11	good	09027	09667	08900	06972	07465	09024	09316	09362	09368	09279	09357	07597	09391	08479	08684	09696
12	good	09007	09425	09050	06073	07465	09061	09309	09357	09270	09281	09357	07597	09157	08429	08684	09568
13	good	09078	09667	08983	08150	06822	08987	09120	09168	09371	09291	09235	07597	09224	08387	08840	09583
14	good	09045	09321	09050	07786	07465	09454	09140	09249	09382	09270	09268	07597	09329	08269	08755	09324
15	good	09056	09258	09050	07924	07462	08680	09297	09342	09144	09274	09266	07597	09262	08539	08820	09630
16	good	09032	09251	09050	07587	07464	09045	09327	09363	09350	09270	09351	07597	09260	08342	08604	09432
17	good	09016	09303	09050	07014	07464	08905	09280	09357	09367	09255	09354	07597	09239	08477	08412	09737
18	general	08982	09412	08900	07673	07465	09012	09146	09245	09365	09275	09265	07597	09275	08386	08678	09506
19	general	08958	09062	09007	07730	07037	09001	09161	09250	09354	09277	09266	07597	09375	08384	08503	09452
20	general	08695	09152	08348	07738	07872	08984	09132	09250	09318	09269	09266	08150	09317	08320	08703	09583
21	general	08891	08816	08921	08121	07465	08877	09324	09361	09160	09281	09351	07597	09360	08465	07906	09555
22	general	08951	09106	09050	06450	07465	08834	09312	09352	09355	09285	09352	07597	09379	08260	08613	09346
23	general	08843	09234	08709	06680	07464	08998	09305	09357	09376	09263	09357	07597	09134	08360	08752	09570
24	general	08857	09232	08709	06642	07465	09273	09318	09358	09371	09254	09362	07597	09314	08607	08698	09701
25	general	08872	09198	08709	07320	07484	08955	09306	09351	09387	09253	09350	07597	09419	08697	08678	09673
26	general	08909	09526	08624	08034	07463	08625	09314	09351	09377	09256	09352	07597	09408	08411	08821	09572

TABLE IV. PERFORMANCE QUALITY STATUS EVALUATION OF 4 MISSILES LAUNCHED BY A DEPARTMENT

number	status level	the whole missile system	I ₁	I ₂	I ₃	I ₄	I ₅	I ₆	I ₇	I ₈	I ₉	I ₁₀	I ₁₁	I ₁₂	I ₁₃	I ₁₄	I ₁₅
27	excellent	09194	09639	09305	06836	07850	08958	09243	09339	09374	09277	09351	08150	09414	08273	08662	09607
28	good	09097	09574	08983	07595	07872	08986	09408	09454	09308	09281	09449	08150	09469	08520	08778	09651
29	good	09041	09613	08966	07263	07465	09004	09166	09254	09371	09281	09265	07597	09370	08459	08698	09660
30	general	08878	09103	08709	08128	07251	08927	09323	09356	09316	09272	09344	07597	09366	08277	08769	09524

After testing the samples, it is found that the predicted results of the 4 missiles are consistent with the actual results, as shown in Table 5.

TABLE V. PREDICTION RESULTS OF SVM MODEL

number	prediction results of SVM	prediction level of SVM	Actual status level
27	1	excellent	excellent
28	2	good	good
29	2	good	good
30	3	general	general
Prediction accuracy		100%	-

VI. CONCLUSION

In the future joint operations, the missile force must face large-scale and efficient operations, which requires that the missile force has the ability to launch mass missiles quickly and accurately. But in the current practice of real missile launch, the traditional method of testing qualified first is usually adopted, although it can guarantee the effect of missile strike, but it is difficult to meet the needs of the real battlefield. In this paper, based on the test data of missile performance parameters and daily management and storage information, using grey theory and linear weighted comprehensive evaluation method, the missile performance parameters are predicted and subsystems performance quality status are evaluated. Finally, on the basis of the in-depth study of the actual missile launch information, Support vector machine (SVM) is used to predict the quality status of whole missile, which provides a way to predict the performance quality of missile. The example shows that this method can accurately predict the performance quality status of missile.

REFERENCES

- [1] Si-feng Liu, Nai-ming Xie. Grey Systems: Theory and Application [M]. Beijing: Science Press, 2008.
- [2] Ju-long Deng. Foundation of GreyTheory [M]. Wuhan: Huazhong University of Science and Technology Press, 2002.
- [3] Wen-jian Wang, Chang-qian Men. Support Vector Machine Modeling and Application [M]. Beijing: Science Press, 2014.
- [4] Jian-feng Wang, Lei Zhang, Guoxing Chen. A parameter optimization method for an SVM based on improved grid search algorithm [J]. Applied Science an Technology, 2012 (3): 28-31.
- [5] Dao-wen Liu, Hai-na Hu. Network traffic prediction based on grid search SVM method [J]. Computer Application and Software, 2012 (11): 185-186.
- [6] Chao Guo, Wei-hua Song, Wei Wei. Stope roof stability prediction based on both SVM and grid-search method [J]. China Safety Science Journal, 2014, 24 (8).