Prediction of Electromagnetic Pulse Irradiation Response Based on Support Vector Machine

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Abstract. Due to the complexity of electromagnetic simulation method based on the mechanism analysis, this paper studies the feasibility of the system identification modeling method based on support vector machine for the prediction of electromagnetic pulse response of electronic equipment, and introduces the genetic algorithm for the model parameter selection. First, we use this method to verify the response of cable irradiated by the EMP. The results show that this method can accurately predict the cable response under different pulse front. Then, we use the experiment data of an UAV electronics system irradiated by the electromagnetic pulse to model and test. The results show that when using the low-amplitude field-strength data as the model training set, the identification model can accurately predict the pulse-coupling waveform under high field strength. The successful application of this method provides a simple and efficient simulation technique for the prediction of electromagnetic pulse response of electronic equipment, which has certain application prospect.

Keywords: Electromagnetic Pulse, support vector machine(SVM), genetic algorithm, field-line coupling; unmanned aerial vehicle(UAV).

1. Introduction
High altitude electromagnetic pulse (HEMP) is characterized by high field strength and wide coverage, which can effectively destroy electronic equipment and important infrastructure, etc [1]. At present, the electromagnetic pulse vulnerability evaluation of electronic equipment is divided into two aspects: experiment and simulation, subject to the limitation of test conditions, in electronic equipment vulnerability assessment often need to carry out a large number of repeatability tests, test period is long and expensive; The HEMP effect experiment is carried out under the HEMP simulator, so it is necessary to predict the coupling response of the equipment under the real HEMP environment. In addition, the HEMP simulator is sometimes difficult to provide sufficient testing field strength environment. Therefore, it is not enough to carry out HEMP effect evaluation by effect experiment alone, but also need to predict and extrapolate the response according to the existing test data.

Numerical simulation can predict the coupling response of the equipment under electromagnetic pulse, which can provide guidance for the experiment and make up for the deficiency of the test [2]. In recent years, the HEMP response prediction method based on system identification has provided a
feasible technique for the HEMP response prediction of electronic equipment. In this paper, support vector machine (SVM) is used as a machine learning method to study the applicability of SVM modeling for predicting electromagnetic pulse coupling response of electronic equipment based on genetic algorithm (GA), which is based on traditional system identification modeling and neural network modeling [3, 4]. The feasibility of this method is verified by experimental data, which enriches the existing electromagnetic pulse response simulation method.

2. Support Vector Machine Modeling Based on Genetic Algorithm

The SVM for system identification is to select appropriate support vector machine model to approximate the actual system. Based on the input/ output data pairs of the controlled system, a nonlinear mapping describing the input/ output relation of the system is obtained by learning. The system identification can be regarded as a function regression problem. Regression Support Vector Machine (RSVM) is used for system identification.

2.1. SVM Identification Modeling Method

In general, nonlinear discrete-time system can be described by nonlinear difference equations, and discrete single-input single-output system is considered.

\[
y(k) = f\left(y(k-1), y(k-2), \ldots, y(k-n), u(k-1), u(k-2), \ldots, u(k-m)\right)
\]

(1)

In the formula, \(u\) is the system input and \(y\) are the system output. \(m\) and \(n\) are the input and output delay respectively; \(f(\cdot)\) is a nonlinear function. The system can be identified by the support vector machine parallel model. The parallel model is:

\[
y_m(k) = f_{\text{SVM}}(y_m(k-1), y_m(k-2), \ldots, y_m(k-n), u(k-1), u(k-2), \ldots, u(k-m))
\]

(2)

In the formula, \(y_m(k)\) is the output of SVM identification model, \(f_{\text{SVM}}(\cdot)\) is a training parallel model based on SVM.

The \(f_{\text{SVM}}(\cdot)\) model of equipment under test can be obtained by training the electromagnetic pulse waveform as input and the response data of the equipment as output. Based on this model, if there is another set of irradiated waveforms, the result of one-step prediction can be used as input of the next time, and the final response output can be obtained by recursion loop, so as to achieve the purpose of prediction. Because the parallel model may cause \(y_m\) to deviate from \(y\) at the beginning of learning and has cumulative effect in the process of recursion, the series-parallel model (with feedback) can be used to train the real system in model identification. Then, the parallel model is used to predict the electromagnetic pulse response of electronic equipment.

2.2. Optimization of SVM Model Parameters Based on GA

To construct a good SVM model, it is necessary to determine a suitable kernel function and select relevant parameters. The results show that different kernel functions have little influence on the performance of SVM, and the parameters of kernel functions are the key factors affecting the performance of SVM. In this paper, the RBF kernel function is used as a universal function, which has good performance and strong learning ability. The regularization parameter \(C\) is also an important parameter to determine the fitting error and prediction error. Too small \(C\) makes the fitting accuracy of samples too small, while too large \(C\) increases the complexity and training time of the network, and ignores the requirement of maximizing the generalization ability. The parameter \(\varepsilon\) of the loss function is insensitive, and it determines the number of support vectors and the fitting precision of the approximation function.

In order to ensure the accuracy of the model, the parameters of SVM need to be optimized because of the proper selection of the regularized parameter \(C\) and the loss function and their parameters. At present, parameter optimization algorithm is widely used to determine model parameters, including
simulated annealing algorithm, genetic algorithm and bilinear grid search method. Referring to the advantages and disadvantages of these algorithms, genetic algorithm is selected to optimize the parameters of $C$ and $\varepsilon$.

The genetic algorithm simulates the above evolution process of organisms, from the beginning of an initial population, the selection, crossover and mutation are repeatedly performed to make the population evolve closer to a certain goal, thus obtaining the optimal solution or the satisfactory solution. The basic steps include: coding, initial group generation, fitness assessment, selection, poor, mutation and termination conditions of 7 steps. In the genetic algorithm parameters of this paper, the values of $C$ and $\varepsilon$ in the gene string are binary coded, the population size is 100, the initial population is randomly generated, and the selection operation is random consistency operation, and the ratio of elite number to cross offspring is 10 and 0.8 in the next generation. The maximum evolutionary band is used as the termination condition and is set to 100 generations.

The purpose of SVM prediction is to make the prediction value fit the actual value as far as possible, the prediction error is small enough, and the mean square error is chosen as the index of the model regression ability. The expression of mean square error is

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (f(x_i) - y_i)^2$$

(3)

In formula (3), $f(x_i)$ and $y_i$ are the predicted and actual values of the $i$ sample respectively. The formula (3) forms the objective function of the overall prediction effect of the support vector machine regression model, and the minimum value is the optimization objective.

3. The SVM Modeling Prediction of Field-Line Coupled Simulation Data

Using electromagnetic pulse irradiated cable, electromagnetic pulse waveform and cable coupled current waveform as input and output respectively, SVM modeling and genetic algorithm model parameters optimization method are used to verify its feasibility in electromagnetic pulse response prediction [5]. In CST cable studio, the different electromagnetic pulse waveform of rising front is defined, and the 2m long cable is irradiated, the diameter of this cable is 1mm, the outer skin is PVC material, and the core cross-section area is 1mm$^2$, the material is copper. The irradiation model and cable cross section are shown in Figure 1 and Figure 2 below.

![Figure 1. Irradiation model](image1)

![Figure 2. Cross section of cable](image2)

The electromagnetic pulse rising front is set to 1ns and 6ns respectively. The pulse radiation waveform is shown in Figure 3. A series-parallel model is used to optimize the parameters, which is shown in Figure 4. The optimal results are $C = 11.707$, $\varepsilon = 0.011$. The response data of rising front 6ns radiation waveform are predicted and compared.
4. Modeling and Prediction of the Electromagnetic Pulse Irradiation Response of UAV

An electromagnetic pulse produced by a bounded-wave electromagnetic pulse simulator is used to irradiate the unmanned aircraft [6]. As shown in Figure 7, the UAV is placed in the electromagnetic pulse simulator's workspace and is fixed vertically with a wooden frame at a height of about 0.5m from the ground. The coupled current on the data line of the engine module and the steering gear module is obtained by measuring system. The electric field intensity of irradiated electromagnetic pulse is set to 10kV/m and 20kV/m respectively. The waveform of pulse electric field and cable coupled current is shown in Figure 8.

**Figure 3.** Pulse irradiation waveform

**Figure 4.** Optimization of SVM Model Parameters

Because the real output of the last time is introduced as feedback, the fitting result is more accurate in theory. In this paper, the string-parallel model is used for identification, and the prediction of the unknown response result is based on the fact that the data of the last time is not used as reference. The parallel model is used as the final prediction result. In order to compare the prediction difference between the two, the contrast diagram between the simulated coupled waveform and the predicted waveform is given in Figure 5 ~ 6. It can be seen from the graph that the parallel model does not cause the model collapse due to the initial error accumulation, but also has high stability and accuracy. And it lays a foundation for the simulation prediction of electromagnetic pulse effect test of electronic equipment.

**Figure 5.** The forecast waveform \((t_r=1\text{ ns})\)

**Figure 6.** The forecast waveform \((t_r=6\text{ ns})\)
The radiation and response data of low amplitude field strength (10kV/m) are taken as the training sample set, the model parameters are optimized, the series-parallel model is used to identify the system, and the parallel model is used to predict the response of high field strength (20kV/m). The prediction results are compared with the actual response results, and the corresponding fitting results are given in Fig.9 ~ 10.

It can be seen from the above diagram that the model is of high precision and that the coupling data under low amplitude field strength can be used to predict the coupling response of electronic equipment under high field strength under the condition that the characteristics of irradiated waveform are basically the same. It is proved that the system identification method based on SVM is feasible in the electromagnetic pulse response prediction of electronic equipments, and it lays a foundation for enriching the electromagnetic pulse response prediction of existing electronic devices.
5. Conclusions
A genetic algorithm-based support vector machine identification modeling method is used to predict the electromagnetic pulse response of electronic equipment. Based on this method, the simulation data of field-line coupling under CST are verified. The results show that the radiation and response data of rising front 1ns can be used as the training set of model, and the response data of rising front 6ns radiation waveform can be predicted accurately. The method is applied to the prediction of the electromagnetic pulse response of UAV cable, and using the 10kV/m radiation waveform and the response data as the training set of the model, the response under 20kV/m radiation waveform can be predicted accurately. Compared with the modeling method based on mechanism analysis, this method has the advantages of simple calculation process, short simulation time and easy engineering application.

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