Predication of Crane Condition Parameters
Based on SVM and AR

Xu Xiuzhong\textsuperscript{1} Hu Xiong\textsuperscript{1} Zhou Congxiao\textsuperscript{2}

\textsuperscript{1}( Mechanical Engineering Department, Shanghai Maritime University, Shanghai 200135, China)
\textsuperscript{2}(China Coal Research Institute, Beijing 100013, China)

E-mail: xuxz\_sj@sina.com

Abstract: Through statistic analysis of vibration signals of motor on the container crane hoisting mechanism in a port, the feature vectors with vibration are obtained. Through data preprocessing and training data, Training models of condition parameters based on support vector machine (SVM) are established. The testing data of condition monitoring parameters can be predicted by the training models. During training the models, the penalty parameter and kernel function of model are optimized by cross validation. In order to analysis the accurate of SVM model, autoregressive model is used to predict the trend of vibration. The research showed the predicted results of model using SVM are better than the results by autoregressive (AR) modeling.

Key words: Feature Vector, SVM, Cross validation, Container crane, AR

0. Introduction

Container crane plays an increasingly important role in port production and logistics engineering, the working condition of crane is very important to safe production and productive efficiency. But the working condition of crane is severe, especially for the rotor and gearbox. The motors sometimes work consecutively without stopping. Because of overload, the motors tend to have mechanical problems. So it is important to predict the working condition parameters of crane motors and know about the real-time information of container crane mechanical properties, which is one of the technical supports for efficient work of port facilities.

Currently, a host of prediction methods come up, e.g. time series modeling, Neural Network algorithm. But these methods require a larger number of samples,
and the extended capability is weak. Support Vector Machine (SVM) is appropriate for the limited sample condition, aiming unlimited samples. The algorithm of SVM \cite{1} will be transformed into a Dual optimization problem. Theoretically, the global optimal solutions are developed, by which the local maximum problem in the Neural Network algorithm can be avoided.

By analyzing the statistic features of vibration signals, the feature vectors of different signals are extracted. The predicted models are established by training vibration signal. The motor feature parameters can be predicted by the models. Compared with the model generated by AR, the model with SVM can get better prediction result.

1. Theory

1.1 SVM theory

SVM is a method based on statistical learning theory, a kind of special small sample analysis theory, which is recently proposed by Vapnik. SVM is based on structural risk minimization, and SVM can avoid the problems caused by Neural Network, such as difficult determination of network structure, over-fitting, less-fitting, local minima, etc. So SVM is regarded as the best solution to small samples prediction and regression. SVM fits in with variety of no-linear function fittings. Function fitting is developed by SVM, after the typical samples (support vectors) is chose.

1.2 Regression and Prediction by SVM

Given a set of data, as the input and meanwhile the objective output, the objective regression function is:

\[
\min_{w,b,c,\xi} \frac{1}{2} w^T w + C \sum_{i=1}^{l} \xi_i + C \sum_{i=1}^{l} \xi_i^* \tag{1}
\]

where \( w \in R^n; b \in R; C \) is a pre-specified value; \( \xi_i \) and \( \xi_i^* \) are slack variables representing upper and lower constraints on the outputs of the system.

The constrained conditions are:

\[
W^T \Phi(x_i) + b - z_i \leq \xi_i \tag{2}
\]
Addition of Kernel function, the dual problem of the objective function is:

\[ \min_{\alpha} \frac{1}{2} \sum_{i=1}^{L} (\alpha_i - \alpha_i^*) Q(\alpha_i - \alpha_i^*) + \sum_{i=1}^{L} (\alpha_i + \alpha_i^*) + \sum_{i=1}^{L} (\alpha_i - \alpha_i^*) \]

The constrained condition is:

\[ \sum_{i=1}^{L} (\alpha_i - \alpha_i^*) = 0, 0 \leq \alpha_i, \alpha_i^* \leq C, i = 1, ..., L \]

and \( Q_{ij} = K(x_i, x_j) \equiv \Phi(x_i)^T \Phi(x_j) \)

Solving the dual problem, the decision function is

\[ \sum_{i=1}^{L} (-\alpha_i + \alpha_i^*) K(x_i, x) + b \]

That is also the regression model.

The normal Kernel functions include the polynomial kernel function, linear kernel function, Gaussian kernel function and RBF kernel function. As the RBF kernel function is better overall performance, this kernel function is utilized in this paper.

The RBF kernel function is:

\[ K(x_i, x_j) = \exp\left(-\frac{\|x_i - x_j\|^2}{\delta}\right), \delta > 0 \]

1.3 Parameters Optimization of Model

Previously, the penalty parameter \( c \) and the kernel function parameter \( g \) are chosen according to the experience or by random. In this paper, how to get the best parameters under the circumstance of cross validation is given. Cross Validation is a kind of statistic analysis method, which is utilized to validate the prediction performance. Specifically, first to divide the data into several groups, one part of groups is used as the training set, the others as the test set. The model is developed by the training data, and then accuracy of the model is validated by the testing data. The performance index is evaluated by the regression accuracy. Cross validation has several branches, among of these methods, the k-fold cross validation is the best one. Specifically, the original data can be separated into k groups (normally to be shared),
every group can be as the testing set, and the rest groups are the train data. After this, k models are got, the performance index is the average value of the accuracy of the k models.

The k-fold cross validation can effectively avoid the over-fitting and less-fitting, and the result is very persuasive. The other method is Grid Search Method. The parameters c and g will be given in a range, calculated by the given c and g, the better parameters are obtained by k-fold cross validation. In the end, the parameters of c and g which gain the best prediction accuracy are the best choose.

High penalty parameter c will cause over-fitting problem, that is to say, the accuracy of train data prediction is good, but the accuracy of the test data prediction is low. So the smaller ones f c and g are more suitable.

1.4 Autoregressive Models

AR time series models are used to describe the acceleration time histories. AR models are a staple of time series analysis and are often used in the analysis of stationary time series processes. A stationary process is a stochastic process, one that obeys probabilistic laws, in which the mean, variance and higher order moments are time invariant. AR models attempt to account for the correlations of the current observation in time series with its predecessors. A univariate AR model of order p, or AR(p), for the time series \( \{ x_t \} \) \((t = 1, 2, \ldots, n)\) can be written as:

\[
x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \ldots + \phi_p x_{t-p} + a_t
\]

Where \( x_t \) are the current and previous values of the series and \( \{ a_t \} \) is a Gaussian white noise error time series with a zero mean.

2. Statistics analysis of the motor real-time operational condition

2.1 The feature of the motor real-time operational data

When the girder of the crane is raised, the motor is out of work, there is no vibration signal, whilst the girder is in plat, because of hosting of container, the motor run and has the vibration signals. And different loads will cause different impulsion and vibration. So the amplitudes of the motor vibration are waved in a wide scale.

2.2 The relationship between vibration and working condition
The motor operating condition is represented by the vibration signal, increased load and mechanical fault will cause increased vibration of the motor and gearbox. When the motor is out of work or the load is reduced, the vibration is decreased. The prediction model is developed by training the vibration amplitude in each motor unit of crane. The trend of vibration change will response with crane motor working condition. So prediction of vibration signal can real the crane condition monitoring.

3. Pre-processing of Data

3.1 Noise Signal Elimination

The data in the paper come from the real-time working condition of the crane motors, so the interference signal is inevitable. The unwanted noise signals will affect the accuracy of analysis and prediction results. So, before modeling interference signal must be eliminated. Followed signal is a kind of data that should be pre-processed. Because the data is real-time information, the analysis of the signals should contact with the operating conditions. In normal circumstance, when the crane girder is risen (out of work), the motor is stopped. The vibration signal is very small and close to zero. But when observing and recoding the girder degree signal, the vibration value of one point is increased. In figure 1. for part of point10000 to 15000, the girder is upright, the motor is out of service, but the vibration has a great value, this data is unbelievable. So, this kind of signal should be replaced by the neighboring data point (figure 2).
3.2 The data normalization

The normalization is to explore the statistical distribution characteristics of the inductive unified samples.\textsuperscript{[3]} As to the probability distribution, the data is normalized to zero and one. And in terms of the statistic coordinate characteristics, the data is normalized to negative one and positive one. No matter to set a model or to calculate, the priority is to uniform the unit. The data samples are trained as the probability distribution in the events by SVM.\textsuperscript{[4]} So the data should be normalized into the value between zero and one.

4. Analysis of prediction results

The model is generated by two signals, the vertical direction vibration signal, the axial direction vibration signal. The training data is the former 1000 points of signal, which is utilized to train the model. And the model can be used to predict the later 100 points of signal. The predict result is compared to the original recording data (figure 3). The plot demonstrates that the prediction by the SVM vibration model generated is good\textsuperscript{[5]}, because the working condition of motor is not stable. The mean squared error of the prediction and the original data is: Mean squared error = 0.103613

In other way the AR model is used to establish the training model, the corresponding vibration signals to be predicted, the prediction results shown in Figure 4. Which predicted results with the original vibration signal mean square error is: Mean squared error = 0.352358. The main reason is that the data is short with AR model.\textsuperscript{[6]} So the vibration SVM model can get a better result.

![Figure 3. predicted result of SVM model](image1.png)

![Figure 4. predicted result of AR model](image2.png)
5. Conclusion

In this paper, by the statistical characteristics analysis of the motor working condition parameters, namely, motor vibration analysis, the feature vector of vibration signal can be got. The prediction model is obtained by support vector machine and autoregressive. By taking these models, the following motor vibration data can be predicted. The different selection of model can get different results. Analysis results show that the SVM model of vibration is better than the AR model.

References:

[1] VladimirN Vapnik, Zhang Xuegong interpret. 2000. “The essence of statistic learning”, Beijing, Tsinghua Universtiy Press

[2] Wang Kai, Zhang Yongxiang, Li Jun.2006. “Fault Diagnosis of Gear based on SVM”, Vibration and Shock.Vol. 16, No.06, pp.25-27

[3] Wang Lei, Zhang Ruiqing. 2009. “Regression Forecast and Abnormal Data Detection Based on Vector Regression”, Proceedings of the CSEE, 385-390

[4] Hu Xiong, Wang Zhixin. 2006. “Vibration feature forecasting on crane motor using support vector machine”, Journal of Shanghai Maritime University. Vol.36, No.27, pp42-44

[5] Chen Xuewu.2005. “The temperature and the temperature increase of motor”, Heilongjiang Science and Technology of Water Conservancy. Vol.25, No.03, pp 37-39

[6] W. W., W. Wei, 2006. “Time series analysis: Univariate and multivariate methods”, 2nd ed Pearson, Boston