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Estimation of self supporting towers natural frequency using Support vector machine

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ABSTRACT: This paper discusses support vector machine for estimation of self supporting towers natural frequency. Decreasing structure vibration range and prevention of dynamic response decreasing are two suitable results in calculation of structures frequency and restricted them to defined values (or their maximize). Recently, support vector machine is used in complex events modeling. This study intends to provide a model in estimation of plate natural frequency using SVM. Structural risk minimization (SRM) principle is used in SVM but in other methods, empirical risk minimization (ERM) is used. In this research, using modal analysis and SAP2000 software, tower natural frequency is studied at the first ten modes. Then, obtained samples are analyzed using support vector machine to provide rules for simulation of estimated frequency in self supporting towers.

***Key words**:* Modal analysis, Resonance, SAP2000 software, Telecommunication tower.

***Abbreviation**:* SRM: Structural risk minimization, ERM: Empirical risk minimization, SVM: Support vector machine.

INTRODUCTION

Using modal analysis, vibration specifications in each system will provide. One of the most important modal analysis application is finding frequency intensification and vibration modes shape in a system (as a structure or one element in mechanical system) (Kumarci and Banitalebi, 2011).

Identifying natural frequency of structure vibration is one of the most important factors of dynamical analysis (Abubakri, 2012). Resonance is a process in which frequency of applied load is equal to natural frequency of vibration. So, if form or dimensions of structure change so that in spite of keeping anticipated efficiency and performance in structure its natural frequency increase, the range of structural vibration and deformation will decrease by dynamic stimulation. It leads to decreasing stress and rising and provides safety in structures. Nowadays, artificial intelligence and support vector machine techniques are used in different sciences and complex modeling. support vector machine technique is a new method which has better performance than old methods such as neural networks which in spite of most of special techniques, it doesn't stop in local maximum and has simple teaching phase. Also, it has accurate calculation in higher data (Ovidiu, 2007). So in this paper the support vector machine is used in calculation of self supporting towers natural frequency.

MATERIAL SND METHODS

Support Vector Machine (SVM) has recently emerged as an elegant pattern recognition tool. This method has been developed by Vapnik (Vapnik and S.Kotz, 2006) and is gaining popularity due to many attractive features. Structural risk minimization (SRM) principle is used in SVM but in other methods, empirical risk minimization (ERM) is used. The results show that in compare with ERM method, SRM method has better function (Cristianini and Taylor., 2000).

SVM is used in two or multi- group classification and regression. Here, to study of SVM model in calculation of self supporting towers natural frequency, 300 towers are used which are analyzed using SAP2000 software. Telecommunication towers are important components of basic infrastructure of communication systems and thus preserving them in events of natural disasters such as sever earthquakes is of high priority. With advances in telecommunication industry, the use of telecommunication towers is rapidly increasing. The proposed self-standing structure consists of aluminum alloy pipes. The trusses at leg location have an outer radius of 0.03 and an inner radius of 0.028m. The braces have smaller cross sections with outer radius of 0.02 and 0.01m. young´s modulus is 7×10^{10} pa and mass density is 2800 kg/m^3. Poisson´s ratio is 0.29 and no pressure is applied. For instance, we considered a telecommunication tower and analyzed it at first ten mode shaped using SAP2000 software. The tower has four floors and height of each is 8m. The base cross-sectional is 2×2m^2. Four base points are fixed on ground.

Figure 1. Unformed geometry of tower

Table 1. First ten modes of telecommunication tower

Mode	1	2	3	4	5	6	7	8	9	10
Frequency	2/4916	2/5562	6/5988	9/0422	10/18	14/478	17/216	18/337	19/725	19/777

Unformed manner of telecommunication tower at first ten mode using SAP200 is shown in figure 2.

Table 2. Study of model on the basis of different parameters of ζ

ζ	Train Set		Test Set	
	R	RMSE	R	RMSE
.5	.9812	.1824	.9829	.1843
1	.9654	.1910	.9902	.1870
10	.9802	.1881	.8971	.1829
50	.9952	.1979	.9910	.1967
100	.9760	.1852	.9784	.1866
200	.9491	.1945	.9665	.1899
300	.9915	.1983	.9472	.1955
$\varepsilon = .001$	C=150			

Table 3. Study of model on the basis of different parameters of ε

ε	Train Set		Test Set	
	R	RMSE	R	RMSE
.0001	.9876	.1771	.9931	.1855
.001	.9922	.1909	.9977	.1841
.005	.9677	.1841	.9855	.1918
.01	.9911	.1791	.9772	.1888
.05	.9920	.1944	.9906	.1904
.1	.9722	.1887	.9833	.1909
$\zeta = 50$	C=150			

Table 4. Study of model on the basis of different parameters of C

C	Train Set		Test Set	
	R	RMSE	R	RMSE
.1	.9923	.1744	.9974	.1947
1	.8989	.1881	.9905	.1961
10	.9369	.1936	.9888	.1877
50	.9772	.1944	.9699	.1948
100	.9872	.1854	.9908	.1893
150	.9912	.1841	.9886	.1966
200	.9765	.1951	.9916	.1947
		$\varepsilon = .001$		
=50ζ				

Modal analysis

This analysis helps to finding system vibration characteristics. It is used in estimation of resonance frequency and shape of vibration modes (in a structure or a member of mechanical system). Deformation leads to vibration. In this manner, when there is no outer force, the structure will be under free vibration (Hughes, ,2004). Structure vibration characteristics including natural frequency and vibration modes are necessary which are calculated by matrix equation:

(1) $$k\phi = \omega^2 m\phi$$

in which k is stiffness matrix, m is mass matrix, ω is angular natural frequency and Ø is vibration mode. K and m matrixes are calculated by structures matrix analysis methods. Choosing the best computer method depends on stiffness and mass matrix characteristics, number of natural frequency and vibration modes. The results of tower modal analysis using SAP2000 software are provided in table 1.

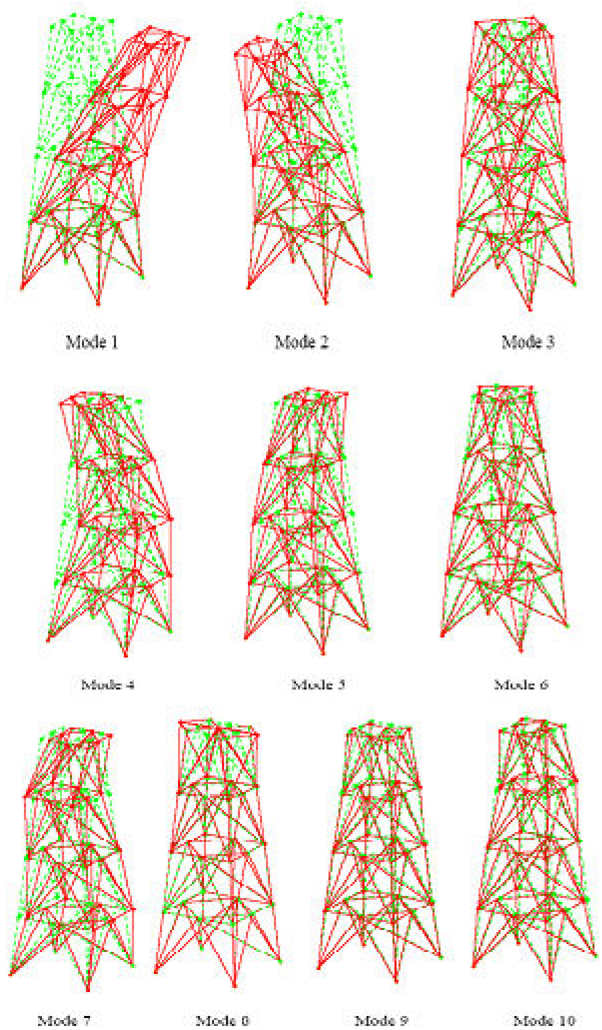

Figure 1. First ten modes of self standing tower using SAP2000 software

RESULTS AND DISSCUSSION

In this method, modeling process include two phases: training and testing. At the end of training phase and using data, generalization ability of trained model evaluates. Briefly, SVM performance in solving regression problem is as follow:

Using a group of linear functions, SVM estimates regression function.

SVM performs regression operation using a function in which deviation of real value is less than permissible ε (loss function).

Using Structural risk minimization (SRM), SVM provides the best answer.

In some methods such as artificial neural networks, empirical risk minimization (ERM) is used to find the best answer. It guaranties the best efficiency of trained data, but there is no guarantee to suitable generalization, so in this network designing method, model generalization is necessary. Optimizing of model generalization and empirical risk minimization (ERM) are contemporaneous events (Huang, Kecman and Kopriva, 2006).

Solving regression problem in SVM is a linear function in form of f(x)=<w.x>+b in a sample such as { $(x_1,y_1),\ldots(x_1,y_1)\epsilon R^n$, y϶R} and can estimated outputs on the base of inputs. Here, X is input function and (w,b) ϵ $R^N \times R$ are controller parameters of "f" function. Also <w.x> shows local coefficient.

For solving regression problem, loss function is used in which minimum error, ε, is negligible. The loss function is as follow (Kecman, 2001):

$$L_\varepsilon(y) = |y - f(x)|_\varepsilon = \begin{cases} 0 & |y-f(x)| \leq \varepsilon \\ |y - f(x)| - \varepsilon & \text{otherwise} \end{cases} \quad (1)$$

Here $L_\varepsilon(y)$ and ε are loss function and amount of permission error in loss function, respectively. Controller parameters in optimum regression function estimates with equation 2 (Ovidius, 2007).

$$\text{Minimise}\Phi(W,\zeta^*,\zeta) = \frac{\|W\|^2}{2} + C\left(\sum \zeta_i^* + \sum \zeta\right) \quad (2)$$

$$y_i - \left((W.X_i) + b\right) \leq \varepsilon + \zeta_i$$

$$\text{Subject to } \left((W.X_i) + b\right) - y_i \leq \varepsilon + \zeta^*{}_i \quad (2.a)$$

$$\zeta_i, \zeta_i^* \geq 0$$

In Eq.2, ζ^* وζ are slack variables. These variables and loss function are shown in fig.2. To solve of optimization problem using Lagrang theory, its function is as Eq.3 (Fradkin and Muchnik , 2006).

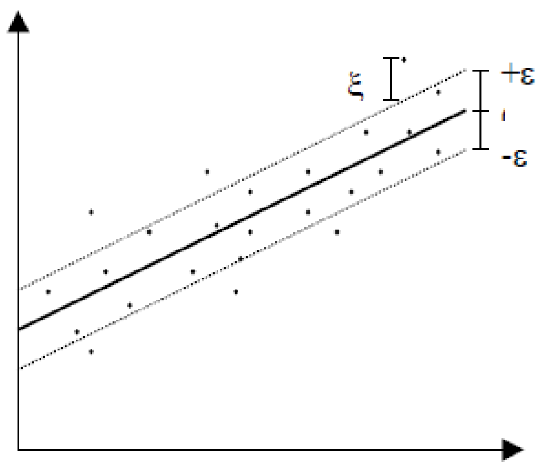

Figure2. Vapnik and Slack variables

$$,L(a^*,a) = -\varepsilon \sum_{i=1}^{1}(a_i^* + a_i) + \sum_{i=1}^{1} y_i(a_i^* - a_i) - \frac{1}{2}\sum_{i=1}^{1}\sum_{i=1}^{1}(a_i^* - a_i)(a_j^* - a_j)(X_i \ - X_j)$$
(3)

According to following data and obtained function maximizing, a, a^* are obtained. These are Lagrang multipliers.

$$\begin{cases} \sum a_i^* = \sum a_i \\ 0 \leq a_i^* \leq C \\ \quad 0 \leq a_i \leq C \end{cases} \quad for \ \ i = 1,2,\ldots,1 \qquad (4\ )$$

by quadratic programming method (QP), so total extremum will provide and because anticipated error of data is more than±ε, so support vectors don't put in ±ε band. It means that ε controls number of support vectors. Using Lagrang multiplier and support vector, controller parameters of optimum response is calculated by:

$$W_{\circ} = \sum_{SUP\ portvectors}(a_i^* - a_i)X_i \quad (5)$$

$$b_{\circ} = -\left(1/2\right)W_{\circ}.[X_r + X_s] \quad (6)$$

$$F(X) = \sum_{SUP\ portvectors}(a_i^* - a_i)(X_i - X) + b_{\circ} \quad (7)$$

In Eq.6, X_r and X_s are support vector (Bennett and Campbell, 2000).

In providing support vector machine, C and ε parameters are defined by user. C is a regulator parameter which accepts 0 to ∞ value. It controls Structural risk minimization (SRM) and maximizing ability of generalization. Also, ε accepts 0 to ∞ values. This value is very important in support vector position and model efficiency. Kernel functions are used in SVM linear regression. In SVM nonlinear regression, controller parameters of optimum function is calculated as follow (Ivanciuc, 2007).

$$W_{\circ}.X = \sum_{SUP\ portvectors}(a_i^* - a_i)K(X_i, X) \quad (8)$$

$$b_{\circ} = -\left(\frac{1}{2}\right)\sum_{SUP\ portvectors}(a_i^* - a_i)K[(X_r, X_i) + K\quad(X_s, X_i) \quad (9)$$

Natural angular frequency

When structure is under deformation, the vibration begins and if external force don't apply, the structure will be under free vibration. To study of structure dynamic response, vibration specifications such as natural frequency and vibration modes are needed.

To study of vibration specifications, following matrix equation is needed:

(10) $$k\phi = \omega^2 m\phi$$

which is obvious. K, M, ε and θ are stiffness matrix, mass matrix, angular natural frequency and vibration modes. M and K matrix calculate using structure matrix analysis method. Choosing the best computer method depends on matric characteristics of mass and stiffness, number of natural frequency and vibration moods.

Estimation of natural frequency

For free vibration in equation of motion (Eq.10) , force vector (f) is 0 (Chopra., 2007):

(11) $$[m]\{u\} + [k]\{u\} = [F]$$

in which k and m are stiffness matrix and mass, u is acceleration function and F is external force function. Using 0 instead of external force function in Eq.10, equation 11 produce:

(12) $$[m]\{u\} + [k]\{u\} = 0$$

In undamped free vibration, bellow equation is obtained:

(13) $$yi = ai\sin(\omega t - \alpha) \qquad i = 1,2,...,ndf$$

In vector manner, we have:

(14) $$\{u\} = \{a\}\sin[\omega t - \alpha]$$

in which ai is motion range of I component and ndf is degree of freedom. In Substitution Eq. 13 to Eq. 14 we have:

(15) $$-\omega^2[m]\{a\}\sin(\omega t - \alpha) + [k]\{a\}\sin(\omega t - \alpha) = 0$$

If $\sin(\omega t - \alpha) \neq 0$, we have:

(16) $$([k] - \omega^2[m])\{a\} = 0$$

This equation is a homogeneous linear equation (right of equation is equal zero) in which ndf and ai are unknown motion and unknown parameter of ω^2, respectively. To obtain nonzero response (ai≠0), coefficient matrix determinant should be 0. It means:

(17) $$\left|[k]-\omega^2[m]\right|=0$$

Data

To network training, 200 telecommunication towers were chose as input. For each tower, seven parameters including base cross section, height of floors, inner and outer radius in truss, Poisson's ratio, Young´s modulus and density were studied. First and second parameters changes by tower dimensions. these changes are varying in the base cross section (2×2 to 6×6 m^2) and height of floors (5 to 14 m). For all towers, third and forth parameters, inner and outer radius in truss and braces, were fixed. Regard to quality of telecommunication tower, fifth, sixth and seventh parameters were fixed.

To access SVM model, data were divided in two groups as 70:30: training and rating (210 samples for training and 90 samples for rating). Considered model and its efficiency in anticipate of population are studied using trained data and inexperienced model (training data), respectively. In this research, Kernel radial basis function (rbf) which is the best Kernel function is used. Here, to provide a model with different parameters of Kernel function (ζ،ℇ and C) , several models are provided and studied. The results of expected model are produced by statistic indexes such as correlation coefficient (R) and root means square error (RMSE). Standard correlation coefficient is used to determine amount of expected and measured values and is calculated as bellow:

)18 $$R=\frac{\sum_{i=1}^{n}(y_i^t-\overline{y^t})(y_i^p-\overline{y^p})}{\sqrt{\sum_{i=1}^{n}(y_i^t-\overline{y^t})^2}\sqrt{\sum_{i=1}^{n}(y_i^p-\overline{y^p})^2}}$$ error, RMSE is calculated:

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}(y_i^t-y_i^p)^2}{n}} \qquad (19)$$

The results of produced models and on the basis of ζ ،ℇ and C parameters are provided in tables 2 to 4.

CONCLUSION

The main goal of this study is to propose nonlinear support vector machine and Kernel radial basis function (rbf) in anticipation of self standing tower natural frequency. For that, for first ten modes, a collection of data for 300 analyzed towers using SAP2000 were divided in training and evaluation in ratio of 70:30. Finally, the best SVM which had the best efficiency in tower frequency response was determined. Kernel function parameters (ζ , ℇ and C), R values (correlation coefficient) and RMSE (root means square error) are determinant parameters in choosing the best SVM.

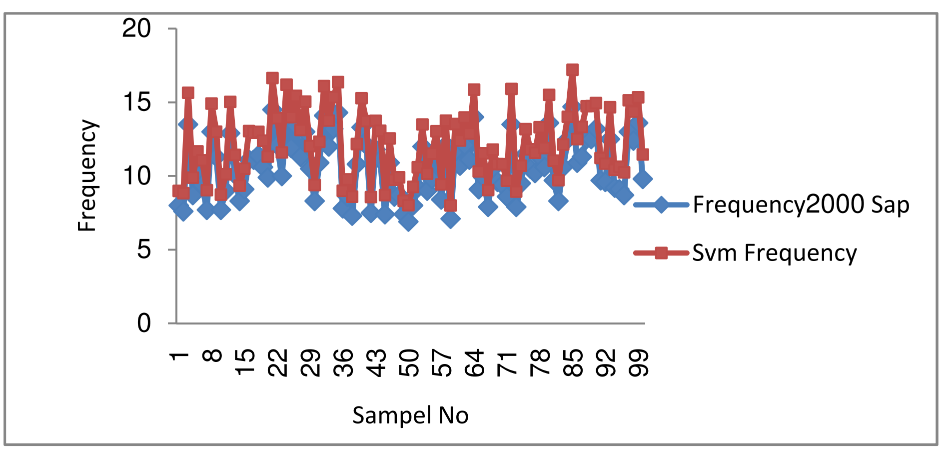

Figure 3. comparing estimated natural frequency of self supporting towers using SVM and SAP2000

Figure 3 shows the difference between estimated frequency by SVM and SAP2000 software. According to results, in estimation of natural frequency of self supporting towers, SVM has 12 to 18 percent error as compare with provided results using SAP2000.

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