Neurocomputing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

# Self-adaptive step fruit fly algorithm optimized support vector regression model for dynamic response prediction of magnetorheological elastomer base isolator

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ARTICLE INFO

*Article history:*
Received 20 July 2015
Received in revised form
25 January 2016
Accepted 21 February 2016

*Keywords:*
Support vector regression
Fruit fly optimization algorithm
Self-adaptive step
Magnetorheological elastomer base isolator
Dynamic response prediction

ABSTRACT

Parameter optimization of support vector regression (SVR) plays a challenging role in improving the generalization ability of machine learning. Fruit fly optimization algorithm (FFOA) is a recently developed swarm optimization algorithm for complicated multi-objective optimization problems and is also suitable for optimizing SVR parameters. In this work, parameter optimization in SVR using FFOA is investigated. In view of problems of premature and local optimum in FFOA, an improved FFOA algorithm based on self-adaptive step update strategy (SSFFOA) is presented to obtain the optimal SVR model. Moreover, the proposed method is utilized to characterize magnetorheological elastomer (MRE) base isolator, a typical hysteresis device. In this application, the obtained displacement, velocity and current level are used as SVR inputs while the output is the shear force response of the device. Experimental testing of the isolator with two types of excitations is applied for model performance evaluation. The results demonstrate that the proposed SSFFOA-optimized SVR (SSFFOA_SVR) has perfect generalization ability and more accurate prediction accuracy than other machine learning models, and it is a suitable and effective method to predict the dynamic behaviour of MRE isolator.



## 1. Introduction

Support vector machine (SVM), based on structural risk minimization (SRM), is one of most commonly used machine learning methods, which is able to analyze data and identify patterns and is applied to classification and regression analysis [1]. Due to the low requirement on training samples, the SVM has the perfect generalization performance regarding small samples and could quickly deal with the problems of local optimum, over-fitting and slow convergence existing in other artificial intelligent techniques [2,3]. Up to present, the SVM has obtained the wide applications in the fields of fault detection [4,5], pattern recognition [6,7], signal processing [8], robotics [9], and machine vision [10]. The SVM was then developed to process the nonlinear regression via the introduction of an insensitive loss function, named as SVR. SVR has been successfully applied to the areas of river flow prediction [11], wind speed prediction [12] and electric load prediction [13]. In the SVR model, the effectiveness and the generalization ability are mainly dependent on two parameters: regularization factor and loss function parameter. Once the values of above parameters are improperly selected, the prediction capacity of SVM will be greatly affected. Therefore, the main problem with SVR rests on the accurate identification of model parameters. There are several approaches developed for selecting the SVR parameters, including gradient-based methods, error evaluation method and gird search method. However, these approaches have similar disadvantages: excessive calculation and time consuming.

Recently, the swarm intelligence optimization algorithms were proposed to tackle optimization problems, which were also applied to optimize the SVR parameters, such as particle swarm optimization (PSO), ant colony optimization (ACO), bee colony algorithm (BCA), firefly algorithm (FA) and artificial fish swarm algorithm (AFSA). In [14], Li et al. put forward a hybrid self-adaptive learning approach based on SVR and PSO to estimate the ore grade. In [15], the SVR parameters are optimized by ant colony optimization, and then the trained model is applied to characterize NOx emissions with high forecast accuracy. Besides, Kavousi-Fard et al. presented a parameter identification approach for SVR using modified firefly algorithm (MFA-SVR), which is able to provide the satisfactory prediction results of electrical load [16]. However, there are still obvious differences between predictions and real data for some days, which signifies that MFA-SVR requires further study and validation.

Fruit fly optimization algorithm (FFOA) is a new swarm

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http://dx.doi.org/10.1016/j.neucom.2016.02.074
0925-2312/

optimization algorithm which is inspired by the intrinsic behaviour of food search in fruit fly swarm [17–20]. The FFOA has been successfully adopted to deal with multi-objective optimization and scheduling problems. In [21], Lin combined the FFOA with general regression neural network (GRNN) to detect the logistics quality and service satisfaction of online auction sellers. This hybrid model is also compared with PSO-optimized GRNN and standard GRNN, and the comparison result demonstrates that FFOA is able to perfectly improve the classification and prediction accuracy of GRNN. In [22], Li et al. proposed a modified FFOA with the introduction of the escape local optimal factor to adjust the parameters of PID control with greatly stable outputs of step responses. In [23], the FFOA was used to solve the homogeneous fuzzy series-parallel redundancy allocation problem. Compared with PSO, GA and Tabu search (TS) algorithm, the FFOA has a relatively quick convergence while the identification accuracy is also higher than that of other algorithms. In terms of these advantages, the FFOA can be considered as a promising candidate for SVR parameter identification.

Magnetorheological elastomer (MRE) base isolator is an adaptive smart device used for vibration control and structure protection from the earthquakes [24–26]. Due to the unique property of controllable stiffness in MRE, the device is able to quickly adjust its property to avoid the resonance and protect the structure with the assistance of the control system [27–29]. Hence, to fully utilize the advantage of the device, an accurate and robust model should be developed for the controller design. However, because of nonlinear and hysteretic force-displacement/velocity responses, how to effectively characterize this novel device poses a challenging task for its engineering applications. So far, several models have been proposed to portray the nonlinear responses of the device, such as Bouc-Wen model [30,31], LuGre friction model [32] and strain stiffening model [33]. These models are designed based on assumption of the device structure. When the model is fixed, model parameters will be calculated using optimization algorithms to minimize the errors between predicted responses and experimental measurements. This type of model heavily relies on the initial assumption, initial values and constraints of the model parameters. Once the information is inaccurate, the identification result may be unrealistic values such as negative damping and stiffness, which will affect the robustness of the designed controller.

On account of the problems in existing MRE models, this paper proposes a SVR-based model to forecast the dynamic response of MRE base isolator. In the proposed model, the captured displacement and velocity together with applied current level are used as the SVR inputs while the output is the shear force generated by the device. To obtain an optimal performance, the FFOA is employed to optimize the SVR parameters, which can make two parameters reach their optimal values in a short time. Considering that the standard FFOA may fall into the local optimum when dealing with some complex problems [34,35], this paper introduces a self-adaptive step update mechanism into the standard FFOA, avoiding the premature and local optimum problems in algorithm. Then, the trained model is utilized to predict the dynamic behaviour of the device based on the inputted information of displacement, velocity and current. Eventually, to demonstrate the superiority of the proposed model, it is compared with other SVR-based models as well as two conventional soft computing methods: artificial neural network (ANN) and adaptive neuro fuzzy inference system (ANFIS). The result validates the proposed model with perfect performance in the evaluation indices.

## 2. Experimental testing of MRE base isolator

### 2.1. Core materials

Magnetorheological elastomer (MRE) is a novel type of field dependent intelligent material, which is made up of magnetic particles fluidized in the rubber matrix [25]. Generally, the MRE acts as a soft rubber without the magnetic field. However, when it is applied to the current, the modulus of elasticity of MRE will be significantly enhanced, which is related to the material property design and applied magnetic field intensity. Due to this unique characteristic, MRE has the great potential to be applied in automatic suspensions, rotor dynamics, motion-based isolator in infrastructure, etc. [28].

### 2.2. Device design

Inspired by the benefits of MRE, Li et al. have proposed an innovative adaptive base isolator based on conventional structure of laminated rubber bearing [25]. The soft MRE material, with significant MR effect, is adopted in this new device, which is demonstrated by great increase of shear modulus when subjected to magnetic field. Fig. 1 illustrates real object and cross-sectional view of the device. As can be seen from the figure, the layout of the MRE base isolator is designed by substituting the traditional rubber with MRE material. In the core of the isolator, 26 layers of steel plate and 25 layers of MRE sheet, each of a 1 mm thickness, are vulcanised together alternatively so as to form a laminated structure. In the core, the MRE sheets endow the isolator great flexibility in the horizontal direction while the steel plates supplies vertical loading capacity to the device. In order to take full advantage of the MR effect of the material, an electromagnetic coil is mounted outside the laminated core so as to generate uniformed magnetic flux throughout the MRE sheets. Therefore, the stiffness of the isolator is adaptable by altering the input electric current of the solenoid and certain relationship between the stiffness and

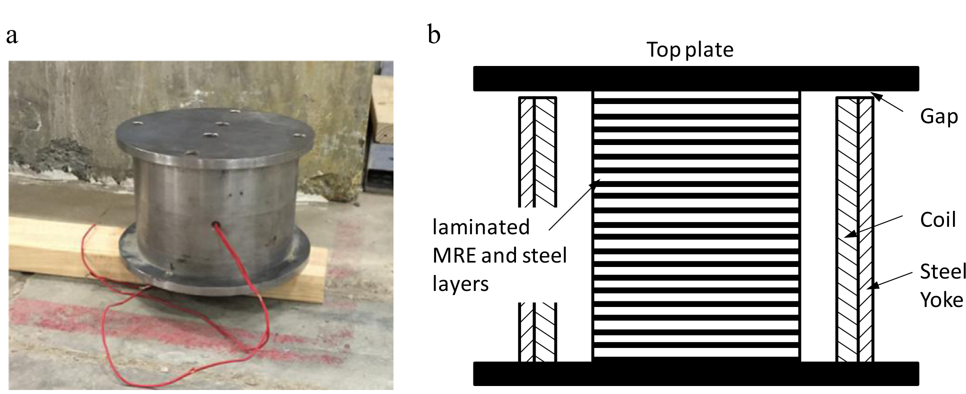


**Fig. 1.** Adaptive MRE base isolator, (a) real objective and (b) cross-section view.

Please cite this article as: Y. Yu, et al., Self-adaptive step fruit fly algorithm optimized support vector regression model for dynamic response prediction of magnetorheological elastomer base isolator, Neurocomputing (2016), http://dx.doi.org/10.1016/j.neucom.2016.02.074