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Evaluation of forces in dynamically loaded journal bearings using feed-forward neural networks

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Abstract: This paper explores the usage of artificial neural networks to evaluate forces acting in dynamically loaded finite-length journal bearings. This practice can significantly accelerate transient simulations of systems that employ such bearings without compromising their non-linear properties. The proposed method utilizes a feedforward neural network, which uses a precomputed database of nondimensional forces for training. This database is supplemented with corresponding relative displacements and velocities of a rotating journal to a stationary bearing shell. The trained network can evaluate the acting forces from the relative displacement and velocities and can be directly implemented to various computational models.

Keywords: feedforward neural networks, submodeling, hydrodynamic lubrication

1. Introduction

Hydrodynamic (HD) forces acting in a dynamically loaded finite-length journal bearing cannot be evaluated analytically. This fact hinders the efficiency of simulation of dynamics in many rotating and flexible multi-body systems because the numerical computation of the HD forces is relatively time-consuming. Some techniques can reduce the computational time at the cost of accuracy. These include database methods based on interpolation of precomputed forces [1], various approximative analytical solutions, and best-fit methods [2].

2. Summary of the Proposed Method

The proposed method vaguely resembles the method introduced in [3]. First, the configuration space of the bearing (CS), i.e., all possible positions and velocities, is generated. Then, nondimensional hydrodynamic forces $\bar{F}^{(i)}$ are numerically computed in a finite number of equidistant interior points of the CS. These nondimensional forces are further transformed using the relation

$$\bar{F}_{ANN}^{(i)} = \mathrm{sgn}\left(\bar{F}^{(i)}\right) \cdot \log_{10}\left(\left|\bar{F}^{(i)}\right| + 1\right), \tag{1}$$

which helps to maintain the same relative accuracy across scales, see Fig. 1a. The database of the transformed forces, together with the CS, serves as a training dataset for feedforward neural networks with a structure shown in Fig. 1b. Hidden layers consist of neurons with a sigmoid transfer function

$$x_{\mathrm{out}} = b_1 + w_1 \cdot \tanh(b_2 + w_2 \cdot x_{\mathrm{in}}), \tag{2}$$

which ensures that the relation between input x_{in} and output x_{out} is smooth.

The networks are trained in a parallel pool using Bayesian regularisation.

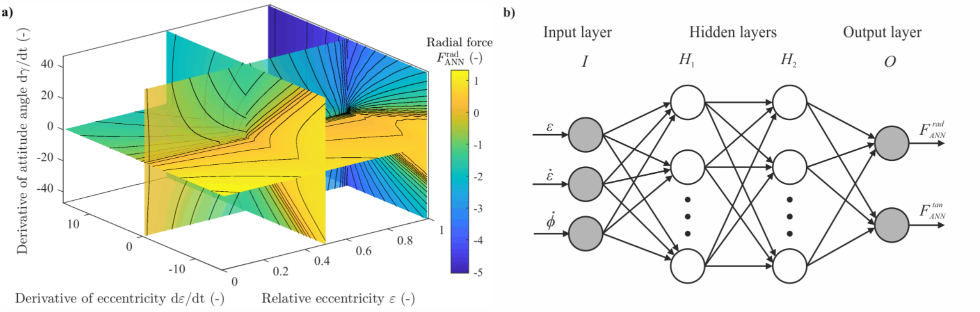

Fig. 1. (a) Transformed dimensionless radial force acting in the journal bearing with length-to-diameter ratio 0.625 and (b) scheme of a feedforward neural network with two hidden layers.

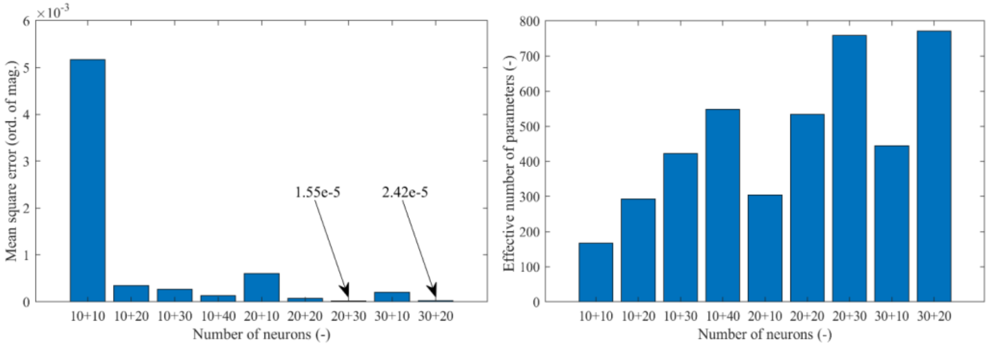

Fig. 2. Mean square errors and effective number of parameters of some trained two-layer networks.

3. Results and concluding remarks

Some results of the training with 132 651 configuration points and 27 000 random validation points are shown in Fig. 2. The networks with as low as 40 neurons have the same accuracy as the regression method introduced in [2]. The higher number of neurons secure even more accurate estimates of the HD forces. Interestingly, the composition of the hidden layers significantly influences the accuracy.

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