A PARAMETRIC STUDY OF ARTIFICIAL NEURAL NETWORK AS A SURROGATE MODEL FOR HEEL-TOE RUNNING COMPUTATION

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INTRODUCTION

Artificial neural networks (ANNs) have been used extensively as a replacement of experiments for many biomechanical studies [1-4]. An ANN can also be used in replace of a numerical model to reduce execution time, such as in solving a computationally intensive problem. However, an ANN is usually applied without strong justification of the construct used, the size of sampling, and etc. This study presents a parametric study of the key factors affecting the network accuracy. The selected network can then be used as a surrogate model for further study.

METHODS

A six-factor heel-toe running model (Figure 1) is used as an example to construct the multilayered back-propagation ANNs. The output of the model is the passive load of the supported leg in the initial impact during heel-toe running [5-6]. There are many factors affecting the prediction accuracy of an ANN. The key factors considered in this study are the size of the data (729 to 46,656) for networking training, the construct of the network (one to three hidden layers), the number of training iterations (epochs), and the type of activation function of neurons.

To verify the accuracy of a trained ANN model, 729 randomly generated data sets from the heel-toe running model were used. The accuracy of a network is determined by root-mean-square error (RMSE) for global validation and maximum error (MAXE) for local justification. The training algorithm is Levenberg-Marquardt method which is a very effective scheme for nonlinear least squares minimizations. The Matlab's Neural Network Toolbox of MathWorks Inc. is used in this study.

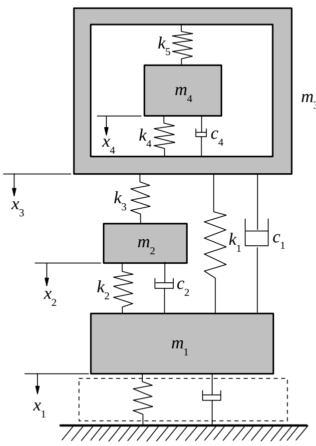

Figure 1: Schematic of the simplified mass-spring-damper model for heel-toe running [5-6].

The construct of a fully-connected ANN is represented by a sequence of numbers separated with a hyphen, the starting number representing the number of inputs, followed by the number of the neurons in each consecutive hidden layer, and ended with the number of outputs. In this study the hidden layers are composed of neurons with a hyperbolic tangent sigmoid activation function, and the activation function of the output layer is the linear function.

RESULTS AND DISCUSSION

It is noted that the size of the data available for training is the dominating factor for model accuracy (Table 1). By using 18 neurons arranged in either one, two, or three layers the best result obtained is the 6-9-9-1 network trained in 2,000 epochs, which has MAXE of 0.946 or 0.689%. Table 2 indicates the networks with two hidden layers having the best prediction capability. The steadily growing complexity of biomechanical models demands more computational power than usual. An accurate ANN based metamodel capable of instant response with high solution accuracy may be helpful in many biomechanical applications.

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Table 1: The RSME and MAXE of the 6-9-9-1 ANN trained in 2,000 epochs.

no. of data	6-9-9-1 ANN	
729 (3^6)	RMSE	1.722
	MAXE	21.2 (16.5%)
4,096 (4^6)	RMSE	0.715
	MAXE	6.38 (4.53%)
15,625 (5^6)	RMSE	0.457
	MAXE	2.54 (2.42%)
46,656 (6^6)	RMSE	0.3317
	MAXE	0.946 (0.689%)

Table 2: The RSME and MAXE of three ANN constructs obtained in various training epochs.

ANN construct	1,000 epochs		2,000 epochs		3,000 epochs		4,000 epochs	
	RMSE	MAXE	RMSE	MAXE	RMSE	MAXE	RMSE	MAXE
6-18-1	1.012	9.582	1.514	10.18	0.678	8.064	4.512	15.14
6-9-9-1	0.906	13.18	0.715	6.381	0.865	9.363	1.356	22.70
6-6-6-6-1	1.062	9.275	1.330	12.37	1.053	10.47	0.863	7.317