Bayesian LSTM Neural Networks for Nonlinear System Identification

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Abstract. System identification offers a valuable tool for creating models of systems from experimental or field monitoring data. When dealing with complex systems, characterized by nonlinearity, neural network based methods have proven potent tools in model discovery due to their flexibility and efficient learning algorithms. Long short term memory (LSTM) networks are a type of neural network which shows particular promise for modeling nonlinear structural systems. Previous work on such methods has been focused on deterministic networks. In this work, we adopt a Bayesian implementation of such an LSTM network, which offers the advantage of uncertainty quantification. Such a Bayesian-LSTM is demonstrated in this work applied to an experimental nonlinear structural system.

Introduction

In modern high performance engineering systems the consideration of nonlinearity is inevitable, especially for systems comprising advanced composite materials or subject to extreme environments. Identification of such nonlinear systems is important for many potential applications, such as control or digital twinning, and yet it remains a considerable challenge to create lightweight and accurate nonlinear models for such systems. Recent work has leveraged neural networks for system identification problems, due to their ability to approximate highly complex systems. Recurrent neural networks (RNNs) are a form of neural network which are specifically designed for dealing with sequence data; LSTM networks, a particular type of RNN, have shown particular promise in the domain of nonlinear dynamics [1, 2]. These works have, however, been limited to deterministic LSTM networks. By exploiting a Bayesian framework, a stochastic LSTM network is rendered, able to predict a distribution on possible outputs rather than point estimates. This is particularly valuable within a digital twinning context, where a digital twin forms a necessary element for supporting decisions on operation and maintenance of engineering assets.

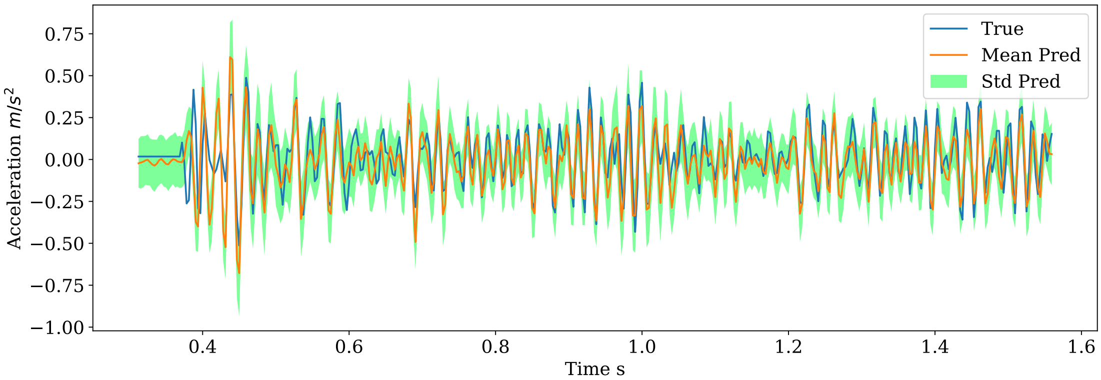

Figure 1: Prediction of acceleration response of 3rd storey to new base excitation input with a Bayesian LSTM, including uncertainty bounds.

Results and Discussion

In this work, we apply a Bayesian implementation of an LSTM neural network for identification of a nonlinear experimental system, namely, a three-storey shear-frame benchmark structure established by the Los Alamos National Laboratory (LANL) [3]. This 3 storey frame structure is excited by random ground motion and nonlinearity is introduced in the form of a rubber bumper acting between the 2nd and 3rd storey, acting as a bi-linear stiffness nonlinearity. We train a Bayesian LSTM to predict the acceleration of the 3 storeys to ground excitation. Some of the experimental runs are used for training the model with others reserved for testing. It is demonstrated that the trained model can successfully approximate the system dynamics by recreating the system response to input time-series not seen in the training set. Simultaneously the Bayesian LSTM can provide estimates of the uncertainty of its response, which are interpretable and useful to the engineer.

References

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