Recurrent Neural Network based Surrogate Modeling of Unsteady Forces Acting on a Plunging Airfoil

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Abstract

Owing to the inherent nonlinearity in flow, both periodic and aperiodic dynamical states are observed in the flow-field of flapping airfoils[1] at various parametric regimes, even when the kinematical model is periodic. Due to significant computational costs of high fidelity simulations of such complex flow problems, developing accurate yet computationally cheap surrogate models for prediction of the aerodynamic forces are of specific interest. Such surrogate models can be used to carry out control or optimisation studies in a robust manner. Traditional time series forecasting methods such as Auto Regressive Integrated Moving Average(ARIMA) are found to model data with underlying linear or periodic relationships better, and therefore might not be best suited for capturing the aerodynamic load behaviour in the aperiodic regimes. Hence, a surrogate model that captures both periodicity and aperiodicity in the force coefficients is investigated. Recurrent neural networks(RNNs)[2] are a class of deep neural networks prominently used for inherently nonlinear sequence modeling problems such as natural language processing[3], video captioning[4] and time series modeling[5]. Hence, in the present study, a RNN based parametric surrogate model is proposed to predict the aerodynamic load coefficients' time histories for unsteady incompressible flow past a plunging airfoil at Reynolds number, $Re = 300$. The reduced frequency(k) and non-dimensional plunging amplitude(h) are the parameters considered for the surrogate model.

Two variants of the model are developed where, (i) given k, h and time histories of the aerodynamic load coefficients for first few cycles, time histories for the next cycles are predicted, and (ii) given only the k and h, the entire time histories of aerodynamic load coefficients are predicted. The effectiveness of the surrogate model variants is demonstrated by comparing the spectral properties of the true and predicted time series and comparing the predictions with that of an ARIMA model for both periodic and aperiodic dynamical states.

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