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A physics-informed machine learning model for reconstruction of dynamic loads

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ABSTRACT

Long-span bridges are subjected to a multitude of dynamic excitations during their life span. To account for their effects on the structural system, several load models are used during design to simulate the conditions that the structure is likely to experience. These models are based on different simplifying assumptions and are generally guided by parameters that are stochastically identified from measurement data, making their outputs inherently uncertain. This paper presents a probabilistic physics-informed machine learning framework based on Gaussian process regression for reconstructing dynamic forces based on measured deflections, velocities, or accelerations. The model can work with incomplete and contaminated data and offers a natural regularization approach to account for noise in the measurement system. An application of the developed framework is given by an aerodynamic analysis of the Great Belt East Bridge. The aerodynamic response is calculated numerically based on the quasi-steady model, and the underlying forces are reconstructed using sparse and noisy measurements. Results indicate a good agreement between the applied and the predicted dynamic load and can be extended to calculate global responses and the resulting internal forces. Uses of the developed framework include validation of design models and assumptions, as well as prognosis of responses to assist in damage detection and structural health monitoring.

Keywords: physics-informed, machine learning, Gaussian process, force reconstruction

1 INTRODUCTION

Assumptions on statistical wind properties, limitations of aerodynamic models and restrictions in stochastic dynamic analysis are just a few of many sources of uncertainties when modelling aerodynamic loads during the design phase of a long-span bridge. Furthermore, due to its extended lifetime and external effects such as climate change, the dynamic forces that are considered during design are subject to unforeseen changes. These factors motivate the creation of models to reconstruct dynamic loads based on measurement data.

Several methods for force reconstruction exist in literature, which are generally based on data-driven techniques [4][5], optimization strategies [10] and defined basis functions [2]. A review of several of these models is given in [8]. A novel methodology based on stochastic processes is proposed in this study. The framework combines data-driven models with physics-based

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