Robust SHM Systems Using Bayesian Model Updating

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ABSTRACT

Structural Health Monitoring (SHM) is becoming increasingly important for monitoring infrastructures. However, one of the main challenges is that the changes due to aging are small, not only for structures, but also for SHM systems. Hence, the question is how should we distinguish such changes due to aging from measurement uncertainty. In this study, laser triangulation sensors (LTSs) are tested and the uncertainty due to temperature effects is studied. Furthermore, time-dependent experiments are performed and the SHM system is calibrated over time through Bayesian Model Updating, considering its temperature dependence.

KEY WORDS: SHM; Bayesian Model Updating; temperature influence; laser triangulation sensor; measurement uncertainties; aging monitoring systems

INTRODUCTION

For condition monitoring of structures, Structural Health Monitoring (SHM) is becoming increasingly important, as it allows continuous condition assessment of the structure and useful supplements on-site inspections (Farrar & Worden, 2007; Wedel & Marx, 2022). The aim of monitoring is to identify changes in the condition of the structure that can only be inadequately detected by the purely visual inspection (Worden et al., 2007), whereby the goal of monitoring can only be achieved by comparing at least two different states: the reference state with the current state (Worden & Tomlinson, 2019). For large infrastructures (e.g., wind turbines or bridges), however, the change in condition due to aging is very small (Klein et al., 2022). Typical measurements in structures are displacement measurements, since changes in the condition of the structure can be detected mainly by relative displacements of individual components (Bergmeister et al., 2015; Marx et al., 2015; Mischo et al., 2022). Laser measurements based on the triangulation principle enable a precise and robust measurement principle in practice, which detects the smallest displacements on the structure and enables contactless measurement (Bartels et al., 2023a; Löffler-Mang, 2012).

A general problem with monitoring systems, however, is that these systems age, just as structures do, and we suspect that the reliability of the monitoring system will decline over time. The question arises how aging of the measurement system can be considered in the data evaluation and how Bayesian Model Updating (BMU) enables a semi-automated data evaluation to give the interpreting engineer a tool that makes the data evaluation easier. This paper provides a contribution to this.

For this, the basic idea of BMU is explained first. Then, laboratory experiments are used to investigate the temperature and time dependence of the measurement system. Subsequently, it is shown how the time-dependent effects of the measurement system is reflected in the measurement data and how these effects can be taken into account in the condition assessment of structures. The semi-automatic data evaluation with BMU is described and potential improvements are discussed. The paper ends with a summary and an outlook.

BAYESIAN MODEL UPDATING METHOD

For engineering problems, mathematical models are typically used to simulate and evaluate the behavior of structures under load conditions. This virtual behavior corresponds only poorly to the real physical structure. To solve this problem, model updating techniques can be applied to update physical input parameters, e.g., material properties of a structure (Worden & Tomlinson, 2019). The physical parameters often cannot be measured directly. Therefore, a model update is required to derive these parameters so that the difference between the mathematical model and the real physical behavior of the system is minimized.

The physical behavior of a system is described by a function \( M(x; \Theta) \), where \( x \) defines the vector of unchangeable model parameters and \( \Theta \) the vector of changeable model parameters to be updated. The mathematical relationship between the requested quantity \( D \) and the prediction model \( M(x; \Theta) \) is defined by

\[
D = M(x; \Theta) + \epsilon,
\]

where \( \epsilon \) describes the model or/and measurement error. The uncertainty