Data analysis using ARX models applied to static structural health monitoring of medieval churches and cathedrals

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ABSTRACT

Slow irreversible deterioration mechanisms affecting masonry heritage structures can jeopardise their structural stability. Static structural health monitoring (SHM), aimed at the continuous measurement of key slow-varying parameters, has the potential to identify such mechanisms at a very early stage. Although this approach can help to design and implement adequate preventive and remedial measures for the built cultural heritage, the application of static SHM systems has been rather limited.

One of the main difficulties that restrain a widespread use of such systems to structures in operation, besides the high costs and complexities related to their long-term character, is the fact that many monitored damage and deformation features (crack openings, inclinations, displacements and deformations) are sensitive to changes caused by environmental conditions [1].

In order to address this issue, this paper describes the implementation of a fully automated data analysis procedure that can be used to filter out the effects caused by environmental variations from complete static SHM systems installed in masonry heritage structures. The first part of the method relies on the identification of models that comprehend an Auto-Regressive output and an eXogenous input (ARX) to represent the dynamics of each monitored response using suitable environmental parameters as predictors [2,3]. A significant benefit of using such models stem from their ability to model time-varying effects, such as those due to thermal inertia, if adequate model orders are chosen. As such, the proposed method also includes a robust automatic process to select suitable model orders that relies on loss functions computed on validation subsets.

In addition, the procedure also evaluates the evolutionary state of each monitored response and classifies them accordingly. The classification is based on the estimated filtered evolution rates and on the errors of the models used to represent the relationship between structural and environmental parameters. One of the main advantages of the classification procedure is that it can greatly facilitate how the estimated evolution rates should be prioritised during prognosis.

The usefulness of the procedure is demonstrated through its application to SHM systems installed in complex medieval structures in Spain [4]. The results from the selected case studies clearly show that the data analysis procedure can help to identify vulnerable areas and contribute to the overall diagnosis of heritage structures.

REFERENCES

[1] Sohn, H. Effects of environmental and operational variability on structural health monitoring. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 365, 539–560 (2007).

[2] Peeters, B. System Identification and Damage Detection in Civil Engineering. (KU Leuven, 2000).

[3] Lorenzoni, F., Casarin, F., Caldon, M., Islami, K. & Modena, C. Uncertainty quantification in structural health monitoring: Applications on cultural heritage buildings. Mech. Syst. Signal Process. 66–67, 268–281 (2016).

[4] Pelà, L., Bourgeois, J., Roca, P., Cervera, M. & Chiumenti, M. Analysis of the effect of provisional ties on the construction and current deformation of Mallorca Cathedral. Int. J. Archit. Herit. 10, 418–437 (2016).