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EARTHQUAKE-INDUCED DAMAGE ESTIMATION IN STRUCTURAL SYSTEMS USING PARAMETRIC PHYSICS-BASED REDUCED-ORDER MODELS

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Structural systems are usually characterized by complex dynamic response under earthquake or damage events, which extends beyond the expected behavior during regular operational conditions, posing thus unique and challenging requirements for designing and utilizing digital twins. Such representations have become indispensable due to the ongoing virtualization, and their efficiency in addressing such phenomena is critical, especially in the context of structural health monitoring applications.

Our work features parametric Reduced Order Models (ROMs) as efficient, low-order surrogates of parametrized structural, dynamical systems and addresses the challenges of adaptive performance and, subsequently, response prediction under state deterioration or stochastic excitation case studies. Specifically, our approach initiates by deriving a projection-based, reliable ROM, reproducing the high fidelity system dynamics, and capturing any parametric dependencies during an initial system modeling stage. To achieve this, we rely on Proper Orthogonal Decomposition (POD) to approximate the subspace of the response from a set of training evaluations and then project and propagate the respective reduced coordinates' dynamics. However, extreme loads like those induced by earthquakes challenge the performance limits of such representations during operating conditions as POD restricts the dynamics in a single, linear approximation of the original manifold [2]. In contrast, the actual excitation may lead to substantially different behavior than the instances observed during the training configurations [1]. As a remedy to this issue, we propose adopting the initial ROM as a forward simulator and adapt the projection basis during operation through a Gaussian Processes Regressor (GPR) coupled to the ROM framework. Relying on monitoring output measurements from a sparse number of system channels, a suitable performance indicator signals the failure of the initial surrogate in the event of extreme operating conditions [3]. In turn, the framework enriches the initial projection subspace by employing the GPR-based scheme, which relies upon data assimilation from the monitoring channels to approximate the deformed configuration of the system and assemble the respective ”damaged” mode. This fusion allows for an adaptive ROM as it enables online projection basis refinement during operation, whilst warning for potential irreversible, or even catastrophic, consequences. In addition, the confidence bounds of the refinement mode prediction enable an initial quantification of the uncertainty involved in the output ROM response estimation.

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REFERENCES

[1] Agathos, K. , Tatsis, K., Vlachas, K. and Chatzi E. (2020) Parametric reduced order models for output-only vibration-based crack detection in shell structures. *Submitted to Mechanical Systems and Signal Processing*.

[2] Lee, K. and Carlberg, Kevin T. (2020) Model reduction of dynamical systems on nonlinear manifolds using deep convolutional autoencoders. *Journal of Computational Physics*, **404**:108973

[3] Tatsis, K. and Dertimanis, V., Papadimitriou, C., Lourens, E. and Chatzi, E. (2017) A general substructure-based framework for input-state estimation using limited output measurements. *Mechanical Systems and Signal Processing*, **150**:107223