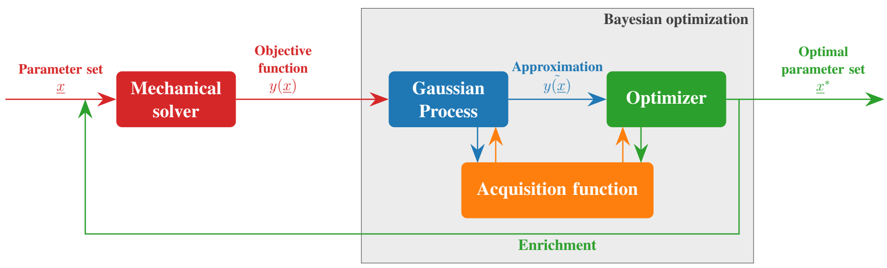
Global Parametric Optimization for Structures with Nonlinear Joints in Vibration

Quentin Ragueneau*,**, Luc Laurent*, Antoine Legay*, Thomas Larroque**, Romain Crambuer **
**Laboratoire de Mécanique des Structures et des Systèmes Couplés, EA 3196, Cnam, HESAM Université, Paris, France*
***INGELIANCE Technologies, Centre de simulation numérique, Mérignac, France*

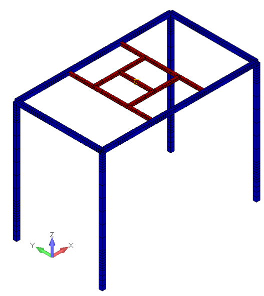
Abstract. The optimal design of complex structures with nonlinear vibration is a significant concern for the industry. This work presents a numerical strategy relying on Bayesian Optimization for the parametric optimization of such structures with the aim of lowering the computational cost compared to classical global optimization algorithm. A specific focus is given on the mechanical solver for the resolution of the nonlinear dynamical problem using the Harmonic Balance Method combined with an Alternating Frequency/Time approach and a scheme for the numerical continuation of the solution path. This mechanical solver is then employed to build and enrich a Gaussian Process within a Bayesian Optimization procedure. The whole strategy is applied to the parametric optimization of a gantry crane.

Introduction

In the process of industrial structure design, numerical simulation combined with parametric optimization algorithms can provide the solution leading to the best performance. Complex assembled structures often include nonlinear phenomena at their joints (contact, friction, etc...) that this study aims at considering to get a more precise model and thus, a more optimal solution while performing a parametric optimization. However, the dynamical simulation of nonlinear models is computationally expensive, and the fullfilment of global optimization, which can require a very large number of computations, on such model could be impraticable in terms of computational time. Therefore, a specific strategy is proposed to make the parametric optimization of structures with nonlinear joints in vibration computationally reasonable. Taking advantage of the fact that only degrees of freedom at the interfaces are nonlinear, the first step consists in performing a Craig Bampton reduction [1]. Then, the solution based on the resulting reduced model is computed using the Harmonic Balance Method with an Alternating Frequency/Time approach [2]. It allows to find periodic solutions with reasonable accuracy avoiding the costly computation of possibly long transients. Numerical path continuation is also applied using a predictor-corrector method to follow the evolution of the solution with respect to the frequency and overcome potential turning points. The computational cost is still quite expensive, and the direct use of classical global optimization algorithm combined with this solver is not practicable especially since the problem includes numerous interfaces degrees of freedom. Therefore, a Bayesian Optimization [3] based on Gaussian Process [4] and an acquisition function is executed to achieve the global parametric optimization with a limited number of calls to the mechanical solver.



(a) Scheme of the Bayesian Optimization



(b) Gantry crane FE model

Figure 1: Parametric optimization of a gantry crane

Results and discussion

The strategy is applied to the parametric optimization of a gantry crane with localized contact. The mechanical solver proves to be reasonably efficient and able to handle the contact nonlinearity and especially to follow the turning points thanks to numerical continuation. The Bayesian Optimization allows to significantly reduce the number of simulations to perform compared to classical global optimization methods such as genetic algorithm.

References

[1] Craig Jr R. R., Bampton M. (1968) Coupling of Substrucutres for Dynamic Analysis. *AIAA Journal* **6.7**:1313-1319.
[2] Sarrouy E., Sinou J. (2011) Non-Linear Periodic and Quasi-Periodic Vibrations in Mechanical Systems - On the use of the Harmonic Balance Methods. *Adv. Acoust. Vib.*. IntechOpen. **Chap. 21**:419-434.
[3] Frazier P. I. (2018) A Tutorial on Bayesian Optimization. *arXiv*. 1807.02811.
[4] Rasmussen C. E., Williams C. K. I. (2006) *Gaussian Processes for Machine Learning*. The MIT Press.