MASCOT-NUM 2022
Clermont Ferrand, France
7-9 June 2022

Bayesian NVH metamodels to assess "pre-design" interior cabin noise using measurement databases

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PhD expected duration: Nov. 2020 - Oct. 2023

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Abstract:

In recent years, a great emphasis has been put on engineering the acoustic signature of vehicles that represents the overall comfort level for passengers. In the automotive industry, we rely heavily on numerical simulation or approximation methods in order to replace expensive and time-consuming real-world experiments. Such numerical methods are not really useful when we are in the early-design stage where very little to no information is available about the different design parameters. Furthermore, the predictive assessment of the vehicle's NVH (Noise, Vibration and Harshness) response is even more challenging due to the highly uncertain behavior that arise from manufacturing tolerances, natural variability in material properties and conditions employed during the physical testing procedures [DSG08]. Owing to such vibroacoustic variability in production cars and various uncertainties in modelling processes, probabilistic metamodels or surrogates can be useful to estimate the NVH dispersion and assess different NVH risks. In contrast to *black*-box models, these *grey*-box metamodels mimic physical behaviors and shall aid as a design space exploration tool during the early-stage design process to support NVH optimization.

An automotive OEM (Original Equipment Manufacturer) such as Stellantis N.V. carries out NVH test campaigns on a regular basis for different needs and diagnosis. These measurement databases constitute different noise contributions such as aerodynamic noise (wind-tunnel test), tire-pavement interaction noise (rolling noise), and noise due to electric motors (whining noise). The first two noise contributions, aerodynamic and the tire-road noise, contribute towards the masking effect which lie in the broadband frequency regime. This research work proposes a global NVH metamodeling technique for mapping the operating input conditions to these broadband noises exploiting the Bayesian framework that takes into account the prior (domain-expert) knowledge about complex physical mechanisms. Both parametric and non-parametric Bayesian Hierarchical models are investigated to represent the level of uncertainty. Additive models based on *Gaussians* and b-splines along with physical laws are used to model the dependency of sound pressure level (SPL) on predictor variables which are further validated using k-fold cross-validation. In addition, Approximate Bayesian Computation (ABC) is also investigated to model the behavior of tire-road interaction noise where the likelihood function is very difficult to formulate due to its dependence on several parameters.

Probabilistic modelling is carried out with the help of a Python package PyMC3 [SWF16] that utilizes No-U-Turn sampler (NUTS). Several different diagnostic tools have been explored to assess the convergence of MCMC sampling process. For model evaluation and comparison of the predictive accuracy, we used Bayesian cross-validation (Leave-one-out, LOO) [VGG17].

Keywords: Bayesian metamodel; Uncertainty quantification; Automotive NVH; Interior cabin noise; Probabilistic programming; MCMC; PyMC3

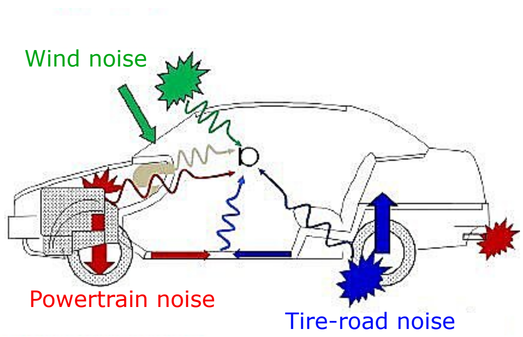

Figure 1: Major sources of noise and vibration in a vehicle

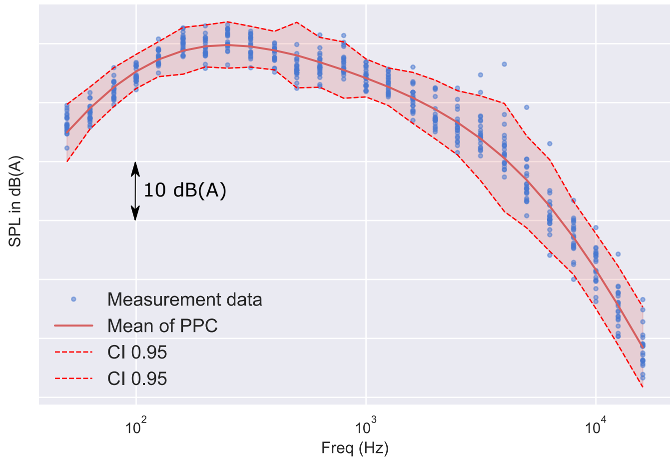

Figure 2: Posterior predictive distribution (PPC) of the observed *aerodynamic* noise levels with the parametric *Gaussian* model; blue dots represent the observed measurement data, solid red line represents the mean of the posterior samples with dashed lines representing the 95% credible intervals

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Short biography – Vinay holds an M.Sc. degree in Computational Engineering from Friedrich-Alexander-Universität (FAU) Erlangen-Nürnberg, Germany. He is currently a Marie-Curie Research fellow at Stellantis N.V., France and enrolled as a PhD candidate at INSA Lyon, France. His research work, funded by the European Commission's H2020-Innovative training network (ITN) under the project ECODRIVE (Grant Nr. 858018), focuses on the development and validation of global meta-models for linking electric powertrain design and NVH performance under uncertainty.