35 Cycle

Uncertainty Quantification For The Assessment Of Human Exposure Around High Power Transfer Systems

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Introduction

Wireless power transfer (WPT) systems are a key factor in the growth of electric mobility. However, the large gap between transmitter and receiver may represent a problem in terms of **exposure to magnetic fields** for passengers or by-standers. The level of exposure needs to be accurately evaluated in order to be compliant with the relevant **standards and guidelines** when designing a new WPT system.

Thus, by using stochastic tools with a given set of inputs and their corresponding outputs, one can build a **metamodel** which interpolates the real model given by the 3D solver. This metamodel will be used afterwards to perform the needed **sensitivity analysis** or **dosimetric analysis**. Such analysis has also been extended to other high-power systems such as **arc welding processes** which can be dangerous for operators.

PCK metamodel

The model output $\mathbf{M}(\mathbf{X})$ can be estimated by :

$$\widehat{M}(X) = \sum_{\alpha\in\mathcal{A}} y_\alpha \psi_\alpha(X) + \sigma^2 Z(x,\omega)$$

where $\sum_{\alpha\in\mathcal{A}} y_\alpha \psi_\alpha(X)$ is a weighted sum of orthonormal polynomials, σ^2 and $Z(x,\omega)$ denote the variance and the zero mean, unit variance, stationary Gaussian process, respectively.

The consistency of our metamodels is assessed using the mean LOO (Leave-One-Out error) :

$$LOO = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\widehat{M}_{/i}(X_i) - Y_i}{Y_i}\right)^2$$

Our sensitivity tracker is the first order Sobol index of the input parameter X_i for the output Y :

$$S_i = \frac{Var[\mathbb{E}[Y|X_i]]}{Var[Y]}$$

If one were to build a metamodel $\widehat{\mathrm{M}}_k(X)$ using a subset of k datapoints out of the aforementioned n datapoints, the accuracy of the predictor on the $(n-k)$ remaining points $\{(X_1, \mathrm{M}_1), \ldots, (X_{n-k}, \mathrm{M}_{n-k})\}$ can be calculated using the OSE (Out-of-sample-error):

$$OSE = \frac{1}{n-k}\sum_{i=1}^{n-k}\left(\frac{\widehat{\mathrm{M}}_k(X_i) - \mathrm{M}_i}{\mathrm{M}_i}\right)^2$$

Acknowledgments

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Submitted and published works

- P. Lagouanelle, O. Bottauscio, L. Pichon, and M. Zucca. Impact of parameters variability on the level of human exposure due to inductive power transfer. IEEE Transactions on Magnetics, 57(6):1–4, 2021.
- P. Lagouanelle, G. Di Capua, N. Femia, F. Freschi, A. Maffucci, L. Pichon, and S. Ventre. Sensitivity analysis in dynamic WPT systems based on non-intrusive stochastic methods. In SMACD/PRIME 2021; International Conference on SMACD and 16th Conference on PRIME, pages 1–4. VDE, 2021.
- P. Lagouanelle, V.-L. Krauth, and L. Pichon. Uncertainty quantification in the assessment of human exposure near wireless power transfer systems in automotive applications. In 2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE), pages 1–5. IEEE, 2019.

Metamodelling complex models

PCK metamodels are used on complex and realistic models to **build accurate predictors** and perform sensitivity analysis. For a complex model (figure 1, only **39 out of 78** datapoints are needed to compute such a predictor and perform an accurate sensitivity analysis.

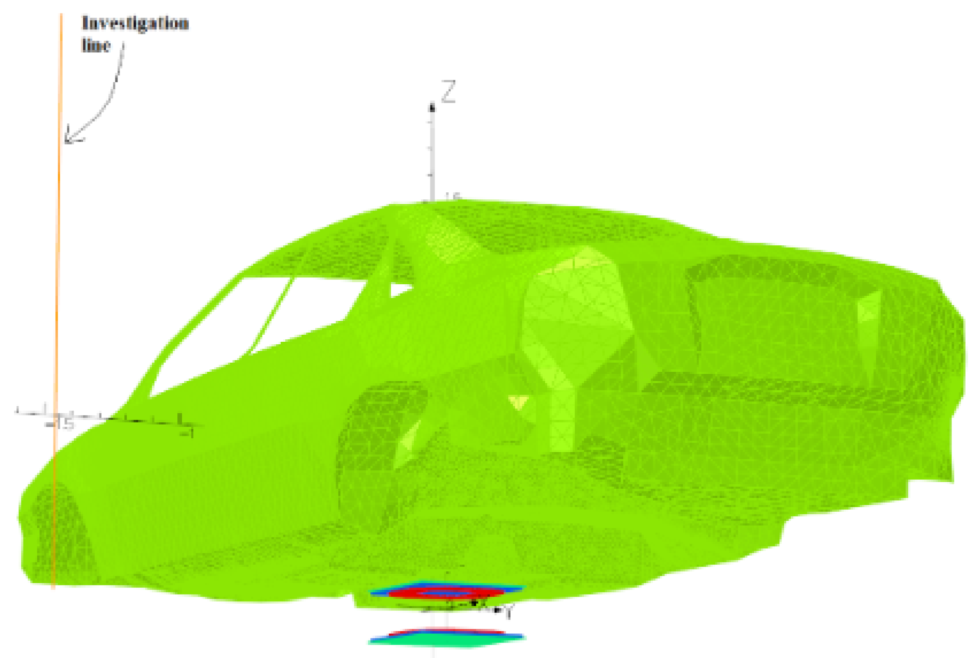

Figure 1: 3D FEM model mesh of the chassis provided by the INRiM

Subset size (k samples)	LOO	OSE	S_{μ_r}
78	2.76e-4	NaN	1.79e-3
58	1.11e-3	4.62e-4	1.67e-3
39	1.53e-2	5.61e-3	2.45e-3
19	4.02e-2	0.248	2.28e-3
S_σ	$S_{\Delta x}$	$S_{\Delta y}$	$S_{\Delta z}$
0.690	2.09e-4	9.67e-2	0.123
0.656	2.55e-3	0.120	0.141
0.581	1.72e-4	0.127	0.231
0.584	4.43e-4	9.70e-2	0.253

Table 1: LOO, OSE and Sobol sensitivity analysis for our second metamodels

Combining PCK metamodels with a **subgridding algorithm** enabled us to compute even less datapoints to perform accurate sensitivity analysis.

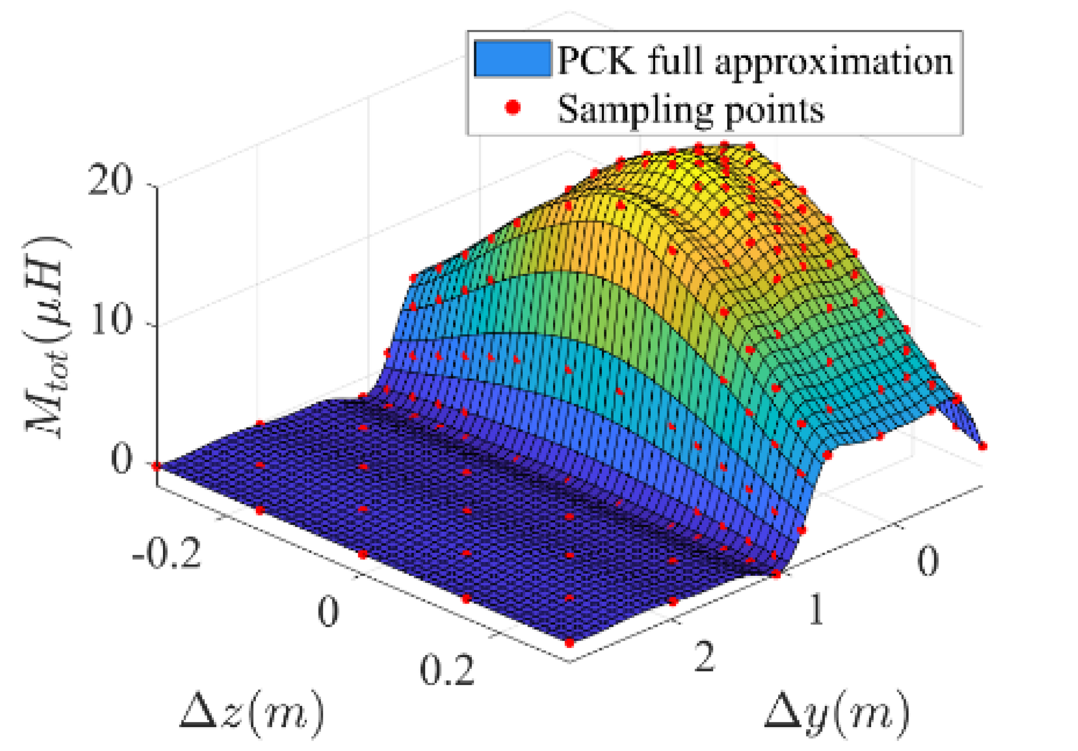

Figure 2: Mutual inductance values for a single pair RX-TX against the longitudinal displacement Δy and the lateral misalignment Δz

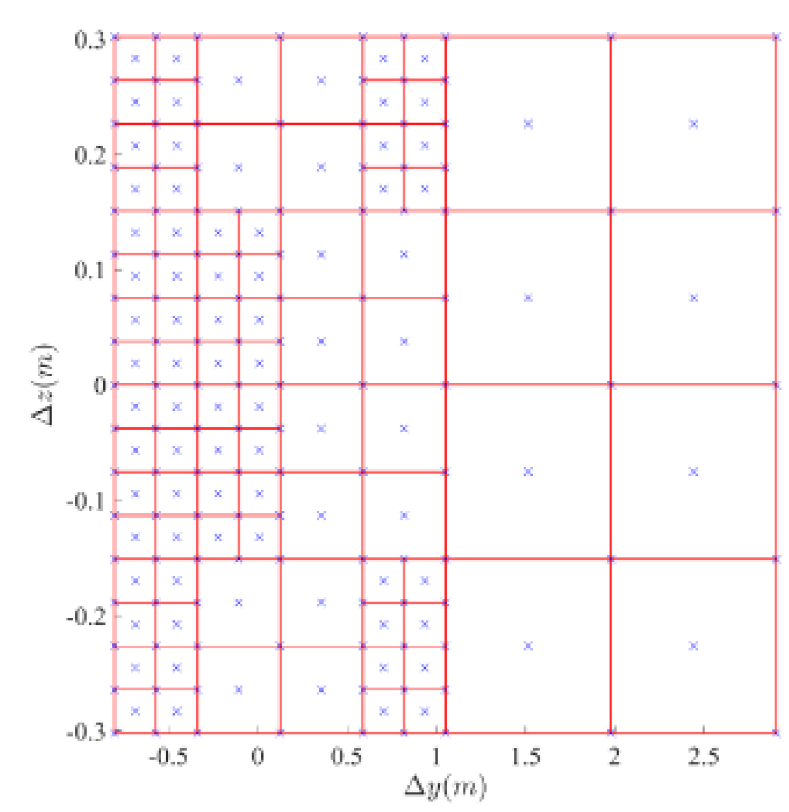

Figure 3: Parameter domains and their corresponding samples used to build the metamodel for the mutual inductance

Metamodelling for human exposure

This analysis has also been extended to high-power transfer systems, and especially mid-frequency direct current (MFDC) welding guns in order to investigate the **human exposure of spot-welding processes**, where a safety area (CF<1) behind the gun can be defined.

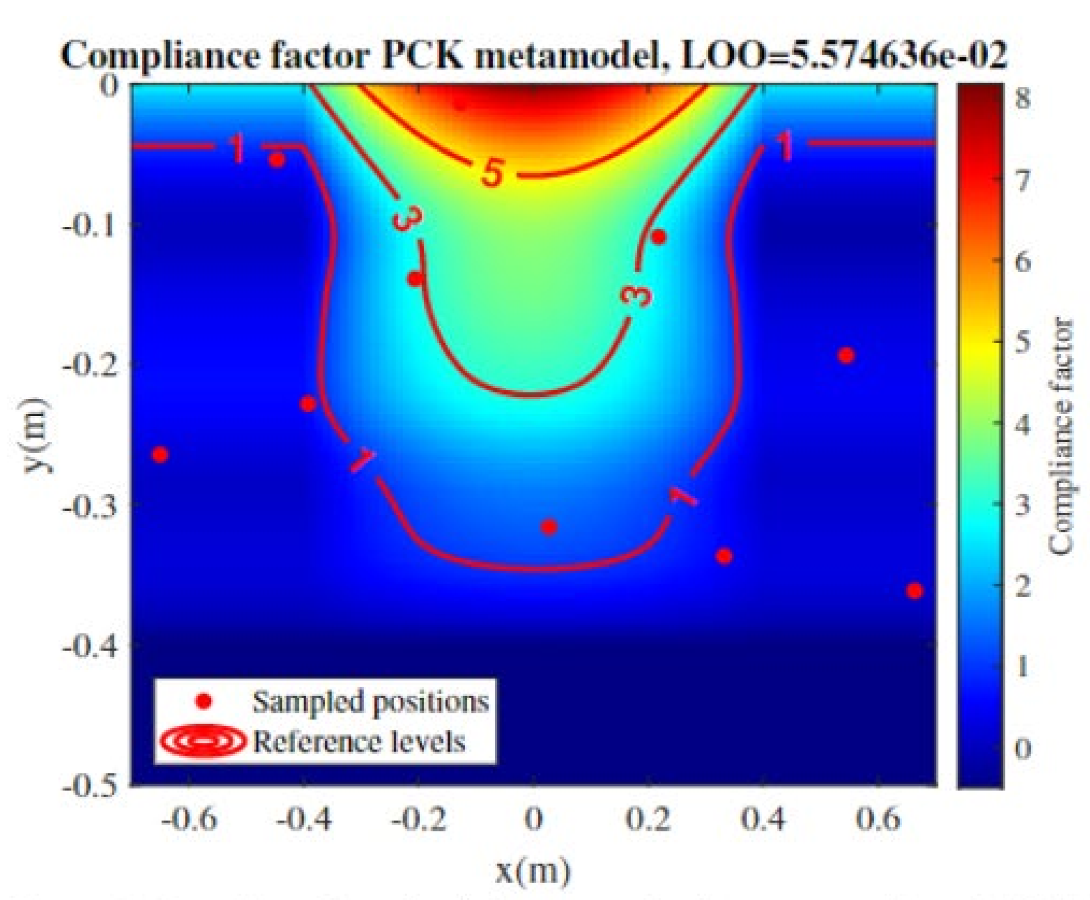

Figure 4: Compliance factor levels for occupational exposure estimated with the PCK metamodel

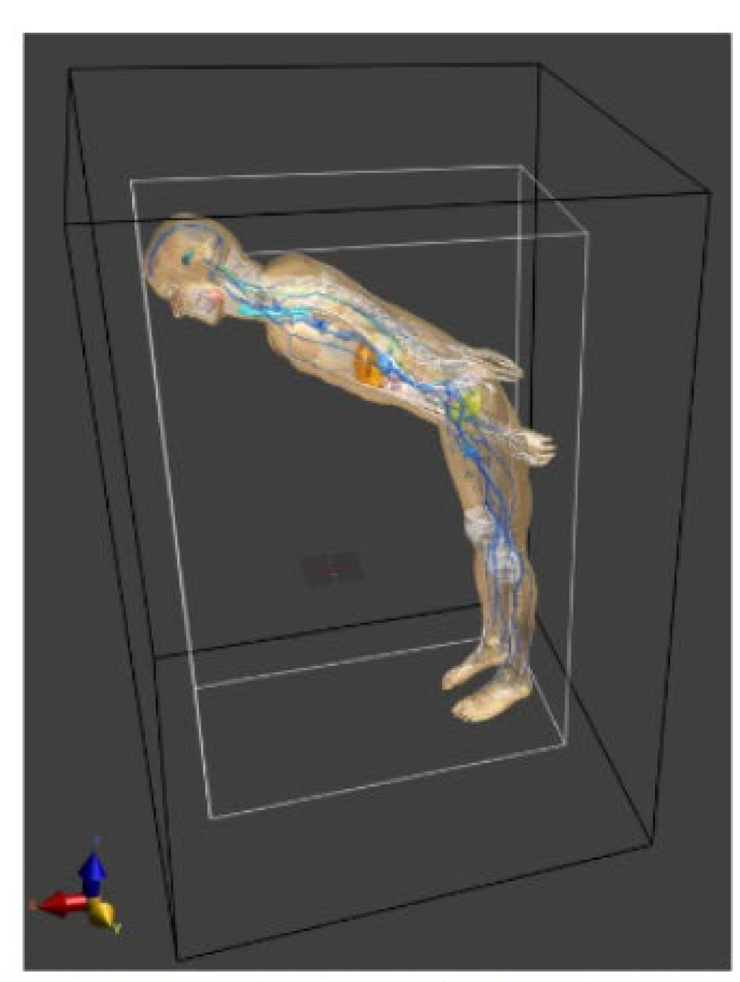

Figure 5: A position for the Duke's model inside the investigation area with Sim4Life

The resulting predictor can also be used to provide some **mitigation solutions** in future designs. Thus, our active learning metamodelling algorithm is currently **combined with optimization processes** in order to find a ferrite design for a realistic WPT system that would insure a compliant system at a low material cost.

PhD program in

Electrical, Electronics and Communications Engineering