Daniela Steffes-lai: Approximation Methods for High Dimensional Simulation Results – Parameter Sensitivity Analysis and Propagation of Variations for Process Chains

Abstract

This work addresses the analysis of a sequential chain of processing steps, which is particularly important for the manufacture of robust product components. In each processing step, the material properties may have changed and distributions of related characteristics, for example, strains, may become inhomogeneous. For this reason, the history of the process including design-parameter uncertainties becomes relevant for subsequent processing steps.

In view of a still high simulation runtime of many physical processes and a huge amount of data to be analyzed, a comprehensive consideration of uncertainties in process chains is not state-of-the-art. Especially, the propagation of all relevant influences due to design-parameter variations from one processing step to the next has not been efficiently possible so far.

To address this, we have developed a methodology, called PRO-CHAIN, which enables an efficient analysis, quantification, and propagation of uncertainties for complex process chains locally on the entire mesh.

A parameter classification procedure newly developed is one of the essential components of the methodology proposed. It characterizes the design-parameters involved with regard to their relative importance and the nature of their influences on the design criteria. Additionally, local effects of the process can be identified using the classification approach. This enables the improvement of the forecast quality in these local regions of interest.

The new methodology introduces an iterative procedure for the extension of the database of simulation results in the case of nonlinear design-parameters to ensure a suitable accuracy. In combination with a compression of the database, this minimizes the computational costs and the memory requirements of subsequent analysis steps.

The compressed database is used in order to predict the behavior of new designs. For this purpose, metamodels with radial basis functions are accelerated by the ensemble compression, which makes the local prediction of the distributions aimed at efficiently possible. Furthermore, we have generalized these forecast models in order to enable the prediction of failure initiation in crash processes.

In conclusion, a local approximation of the probability distribution function becomes possible. Therewith, for example, the median and additional

quantiles can be taken into account on the entire component in an optimization task in order to achieve a robust design.

Moreover, we have derived an estimator of the average approximation error in a predicted new design in a single processing step, which is computed directly within the new methodology. An additional estimator of the maximal approximation error for the entire process chain has been derived theoretically.

Bringing all individual components together, the newly developed methodology enables the propagation not only of single results, but also of all relevant influences of design-parameter uncertainties from one processing step to the next. We demonstrate that a considerably better forecasting quality of the final processing step is achieved using the new methodology.

The PRO-CHAIN methodology developed is applied to industrial applications from the automotive industry. Particularly, a complex forming-to-crash process chain is investigated. This demonstrates the efficiency and the benefits of the methodology proposed compared with state-of-the-art quasi-Monte Carlo methods. Especially, we illustrate that important influences due to design-parameter variations have been detected, local effects have been characterized, and a possible failure of the component has been predicted properly using the innovative methodology.