Success Story
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Innovative Statistical Method for Time-Efficient and Robust Modeling of Computer Experiments

Improving the reliability of sensor devices while simultaneously keeping the production costs at a minimum is one of the main challenges in modern industry. The process of designing such systems is mostly based on very complex computer simulation models where the calculation time of one particular system can be immense. This makes it almost impossible to use standard optimization methods that need a huge amount of different simulation runs to find appropriate system configurations. CTR developed an innovative statistical method that can be performed on a comparably small number of simulation runs. Besides presenting an overview about the general behavior of the underlying physical system, this method also offers the opportunity to perform time-efficient optimization of computer simulations.

Background: Design of Computer Experiments

One of the key challenges in modern science is finding solutions to mathematical models that describe high technology processes. Such systems often cannot be solved directly and need to be approximated by computer simulation techniques like the Finite Element Method (FEM). However, the complexity of the underlying problem also increases the computing time of FEM, where the simulation of one particular system configuration can last for hours or even several days. This becomes especially problematic when dealing with optimization tasks that typically require many subsequent evaluations of the system. To address this problem, it is the aim to get a maximal amount of information from a minimal number of costly computer simulation runs. In classical real-world experiments such approaches are summarized in the well-known design of experiments (DOE) theory, but as real-world measurements differ from simulation data by the deterministic nature of the latter, this theory must be adapted to be used on simulation data, which is then known as "design of computer experiments". This methodology describes a two-step process, where in a first step it is decided for which system configurations the computer simulation must be performed and in a second step a statistical surrogate model that describes the overall behaviour of the physical system is constructed from these simulation runs. The optimization task can then be performed on the statistical model, which is much faster than using only simulation runs, see Fig.1.

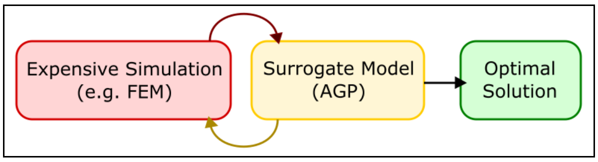

Fig. 1: Flow chart of the optimization approach based on surrogate models.

bmwfw Federal Ministry of Science, Research and Economy
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It is well-known that Gaussian process models are the method of choice to describe such simulation data, as they are more flexible than many other interpolation and fitting methods like splines or polynomial fits. However, standard Gaussian process models must often deal with instable correlation parameter estimates and become difficult when dealing with higher dimensions.

Development and Validation of Robust Additive Gaussian Process Models

A new approach was developed at CTR, based on additive models and Gaussian processes. It features all the advantages of Gaussian processes to construct excellent surrogate models based on a minimal number of input data points and avoids the dimensional problem by the new additive structure. Furthermore, the parameter estimation problem is solved by introducing the principle of robustness from Bayesian statistics.

The Additive Gaussian Process (AGP) model has been already tested and validated on three different test-functions up to five dimensions and it always outperformed normal Gaussian process models and other standard methods.

Impact and effects

The usability of the AGP model was validated on a small, simplified magnetic position and orientation sensor system. This is of special interest as one must often use costly FE simulation when soft-ferromagnetic elements are included or non-linear material parameters must be accounted for. Our example is based on a linear position detection system with an AlNiCo magnet, where the non-linear demagnetization curve requires the use of FE simulations.

The main goal is to maximize the sensitivity of the sensor system. At the same time we want to minimize the volume of the magnet for optimal cost-efficiency, yet to keep the amplitude above some specified value for ensuring a trustworthy sensor output. Fig.2 shows the FEM input data (left) and the AGP prediction (right) for a cylindrical AlNiCo magnet where the parameters of interest are the radius *r* and height *h* of the magnet.

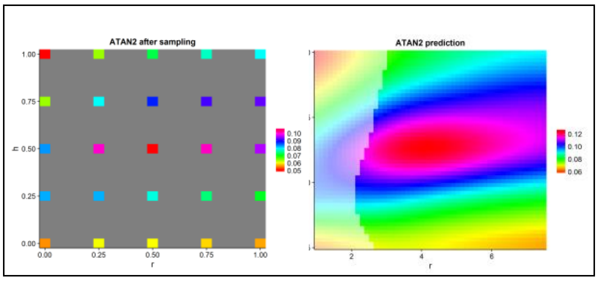

Fig. 2: Right plot shows the AGP prediction based on the 25 sampled FE data points shown in the left plot. The shaded region defines parameter settings were the amplitude is too small.

The optimal values given by the AGP model are now easily found. As the error rate was very small (maximum error is below 10%, and error in the region of interest is close to 1%), this simplified case study demonstrates successfully that the AGP model is capable of getting good predictions out of a limited set of simulation points. Based on this success we aim to further improve the simulation model and use it to solve more complex problems.

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