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ATENÇÃO! As respostas às questões deverão ser redigidas em PORTUGUÊS.

Questions 01 to 05 refer to the text below.

APPLICATION OF MACHINE LEARNING PROCEDURES FOR MECHANICAL SYSTEM MODELLING: CAPABILITIES AND CAVEATS TO PREDICTION-ACCURACY

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Introduction and background

Today's engineering tasks are usually part of multi-parameter, -level and -physics processes. Numerical models and simulations are often applied in development processes. Common to all model-based approaches is a certain calculation procedure that contains one or more variables which are used to create the link between the model and a real counterpart. A drawback of these numerical simulations is also commonly known. They are only able to deliver "one result" for a given input. A simulation outcome using average material parameters for a nominal geometry represents therefore an *average result*.

Model optimization updates material parameters of an available FE-model to fit better to experimental data. But getting closer to one measurement is also not sufficient looking at a series of products. Manufacturing requires tolerances, which lead to inevitable variations of the final geometry. These variations result in a scatter of characteristic properties of the product. They are not deterministic—therefore the resulting scatter also is uncertain. The authors describe a procedure to predict the frequency scatter for Low-Pressure-Steam-Blades under different operating conditions. The task here is a prediction of a max. deviation from nominal data, which also requires a model-based optimization method. A third application of models is product optimization. Optimization routines try to find an optimum (nominal) solution. All applications are dealing small changes in input-values to reach a local or global minimum. Direct optimization on numerical simulations is possible, but it may also be expensive in computational effort. To reduce effort and speed up development iterations, model based optimization may be used. Another demand for efficient but accurate predicting models are whole-system models for automation purposes. Full detailed models are not applicable in this scope as numerical effort contradicts real time requirements.

This variety of applications requires models to be established, which are capable to predict the characteristics of the (expensive) full featured-models with reduced effort. As the deviations from the nominal value are relatively small compared to the characteristic values, high accuracy and still physical valid prediction methods are required. From a system modeling standpoint different approaches are available. This study presents several methods, highlights and discusses their capabilities, efficiency and influences on accuracy.

System modeling

Usually system modeling is based on a presumed structure represented by a certain **model equation** with a **number of model parameters** (nsysnsys). Similar to the material parameters of an FE-model, these model parameters are unknown. Prior to transferring the model to a productive state, they have to be defined appropriately. Engineers often call this approach *grey box* model.

As the exact physical functions are most probably not known analytically, they are fitted by a polynomial sum. Such a polynomial is written $f(x)=\sum i=0daixi=a0+a1x+a2x2+\cdots f(x)=\sum i=0daixi=a0+a1x+a2x2+\cdots$ as a sum of infinite number of elements. The variable *x* represents a single system parameter of the system to be modelled. In a real application the sum often does not contain a high number of degrees *d*.

To identify the **model parameters** (aiai), experimental data is usually fitted by a *Least Square Fit method (LSF)*. With a certain number of measurements, the function values f(xmeasured,i)f(xmeasured,i) at a location *xmeas,ixmeas,i* are known. For a good fitting, a higher number of measurements than the actual number of model parameters *npolynpoly* should be used.

Machine learning

Artificial Intelligence (AI), *Machine Learning (ML)* and *Deep Learning (DL)* are frequently used words today. AI basically deals with data handling and analysis. The different levels of the models require different amounts of data for application. DL, using neural networks with many layers, requires most data, ML requires less. ML can be subdivided in *Supervised Learning* respectively *Unsupervised Learning*.

In the scope of this study supervised learning techniques were applied. An outcome of an ML-procedure is a tool which can be applied for making decisions or predictions. At this point we are close to system modeling. Both methods are using an algorithm for making predictions and both use empirical data to define model parameters. In contrast to this modeling approach, *Artificial Neural Networks (ANN)* do not prescribe a certain structure, they are closer to a “black box”-model type.

Methods, procedures and models

This section starts with a description of the applied methods and calculation procedures used in the present study. Then modelling techniques from classical engineering and ML packages are described briefly and compared regarding their capabilities. Finally, three sample problems are introduced, which are used to demonstrate and discuss influences on model accuracy.

Automated calculation procedure

The automated calculation procedure applied in this study uses data from a numerical experiment during development to derive a simplified model. This model is then used for system optimization or predicting deviations of certain system characteristics. The focus for the newly developed software package is being versatile and not bound on a specific application, underlying software or design target. This is demonstrated here using different FE-software and meshing procedures.

The procedure is divided into four steps: Data creation, System Modeling, Analysis of system characteristics, Validation of models and results. The data creation is done by using a *Numerical Experiment*. Required for this is a parametric numerical model, which may either be an FE- or a CFD-analysis. The parametric system includes *nsysnsys* different **system parameters**. For example, geometrical dimensions, material parameter or layer-directions for fiber reinforced plastics. During preprocessing of the numerical experiment, the model is modified by random input data within reasonably defined boundaries. This is leading to *ncalcncalc* different calculation runs for the underlying model. After solving, relevant characteristic data (for example natural frequencies or stress values) is extracted and gathered in adequate data-files.

With the second step the model identification is performed. This is done by combining and least-square-fitting the random-input- in conjunction with the characteristics-output-data. Details and results of feasible accuracy is the main topic of this study and will be described later.

In the third step, the identified system is used to do further analyses. The main advantage to the underlying numerical simulation is a significant reduction of computational effort. Using the simplified model therefore leads to quick and efficient calculations. Optimization, model updating of the numerical simulation to match characteristic-targets or prediction of spread for characteristic values is feasible. The latter application represents the focus of.

For the later shown sample problems, a sensitivity study and max. deviation search will be performed. As an optimization result is highly dependent on the model-accuracy, this study puts a focus on comparing model accuracy of the models discussed. To validate the prediction results, the fourth and final step is done. The optimized system parameters *nsysnsys* are fed back to the FEA and calculation results are compared.

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Question 1

Explain why, according to the authors, model-based optimization is a better fit for the study in question than direct optimization on numerical simulations.

Espaço para Resposta

Question 2

Distinguish the “grey box” model approach from the “black box” model approach, according to the authors.

Espaço para Resposta

Question 3

According to the text, how do *Machine Learning and Deep Learning* relate, and how do they differ?

Espaço para Resposta

Question 4

Describe the four-step procedure implemented by the authors in the newly developed software package proposed in this study.

Espaço para Resposta

Question 5

- Translate the excerpt below in the space provided.
- The translated text should be clear and accurate in terms of structure and meaning.

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