Hybrid modeling for complex dynamical systems

Background

A common approach to modeling dynamical systems is to construct models from first principles. These models offer physical insight, but perform poorly if the dynamics of a system are not properly understood.

Data-driven black-box modeling techniques offer accuracy without the need for in-depth physical insight, however, they require that the dynamics of interest are properly captured in the sample data.

Hybrid modeling is a methodology that was introduced in order to remedy the shortcomings of both the aforementioned techniques. It is performed by allowing the known dynamics of a system to be modeled through first-principles, while unknown dynamics are discovered through data-driven black-box modeling. This improves both accuracy and extrapolation over the previous methods, while reducing the amount of system knowledge and sample data needed.

Aim and Objectives

The aim of this project is on exploring the use of hybrid modeling techniques in modelling complex dynamical systems.

Specifically, hybrid modelling techniques have been shown to work well for simulation based test cases, but they have had trouble with handling the noise levels and uncertainties presented in real systems. Thus, this project will focus on the use of hybrid modeling to achieve accurate and interpretable models of both synthetic and real systems.

The project will consider questions such as:

How is uncertainty and noise affecting the model, and how can the effects of it be reduced?

What challenges do we face when performing hybrid modeling on a synthetic vs a real system?

To what extent can unknown dynamics be made physically interpretable?

Under what circumstances do hybrid models outperform other techniques?

The project will be focused on the analysis of a certain class of thermodynamical systems; a metal rod that is connected to an adjustable heat source. This system can be seen as an oversimplification of the much more complicated class of industrial metal processing furnaces, where the complexity of the system results in a poor understanding of the dynamics. Both a real implementation of the system and a first principles model has to be constructed.

The overall structure of the project is as follows:

1. Design and construction of hardware
2. Construction of an equation based first-principles model
3. Experiment design and data sampling from the real system
4. Hybrid model identification and analysis

Supervisors

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Prerequisites

The recommended prerequisites for this project are

- Knowledge of statistical learning methods
- Some knowledge of equation based modeling and Finite Element Analysis.

References

[Glassey and Von Stosch, 2018] Glassey, J. and Von Stosch, M. (2018). *Hybrid modeling in process industries*. CRC Press.

[Sohlberg and Jacobsen, 2008] Sohlberg, B. and Jacobsen, E. (2008). *Grey Box Modelling – Branches and Experiences*, volume 41. IFAC.