A Framework for Automated, Data-Driven Digital Twin Derivation from Multiphysical Simulation Models

Extraction of highly accurate and faster-than-real-time digital twins from existing simulation models with only one-to-two training data sets.

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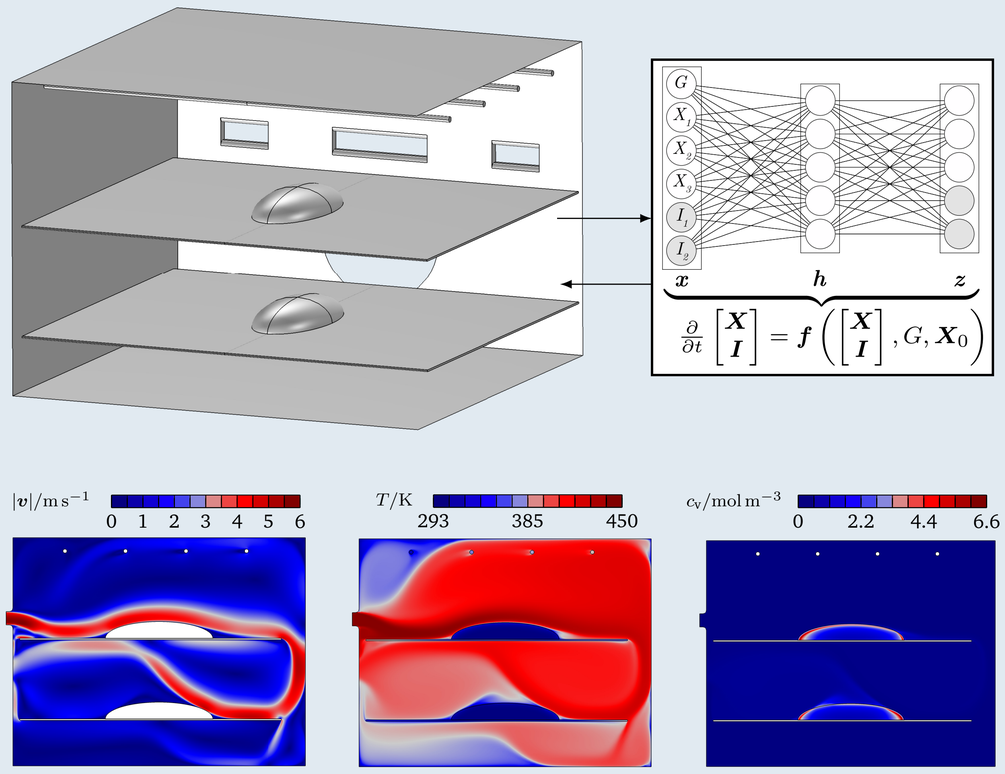
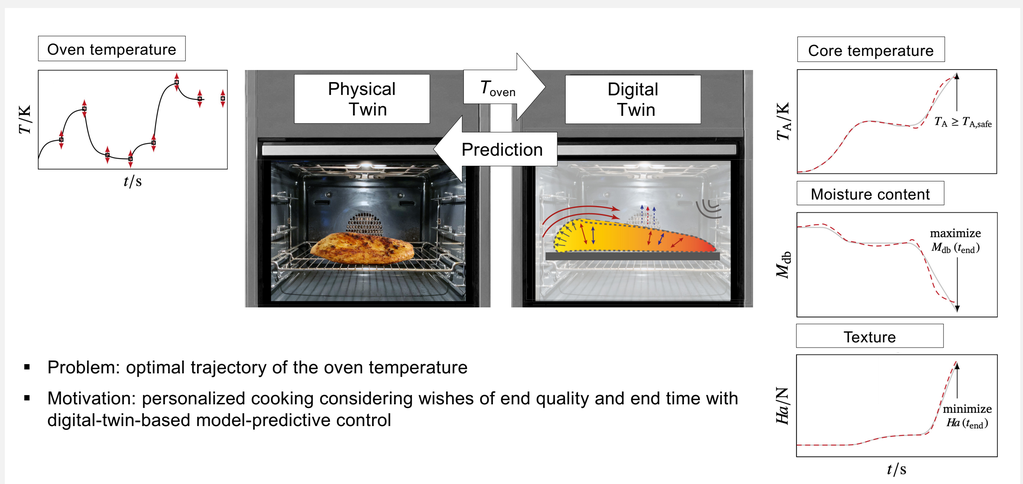


Process Autonomy with Digital Twins

A digital twin is a virtual set of information replicating its physical counterpart at the utmost fidelity. Digital and physical twin benefit from bi-directional data exchange that occurs in real time and over the whole process lifecycle. Digital twins symbolize the endeavor to make simulation insights available to the process that is in operation, such that it might make better-informed, autonomous decisions. Consider, for example, autonomous thermal food processing.

"Alexa, tell the oven to prepare my meat medium-rare for 08:15 p.m."



- Problem: optimal trajectory of the oven temperature
- Motivation: personalized cooking considering wishes of end quality and end time with digital-twin-based model-predictive control

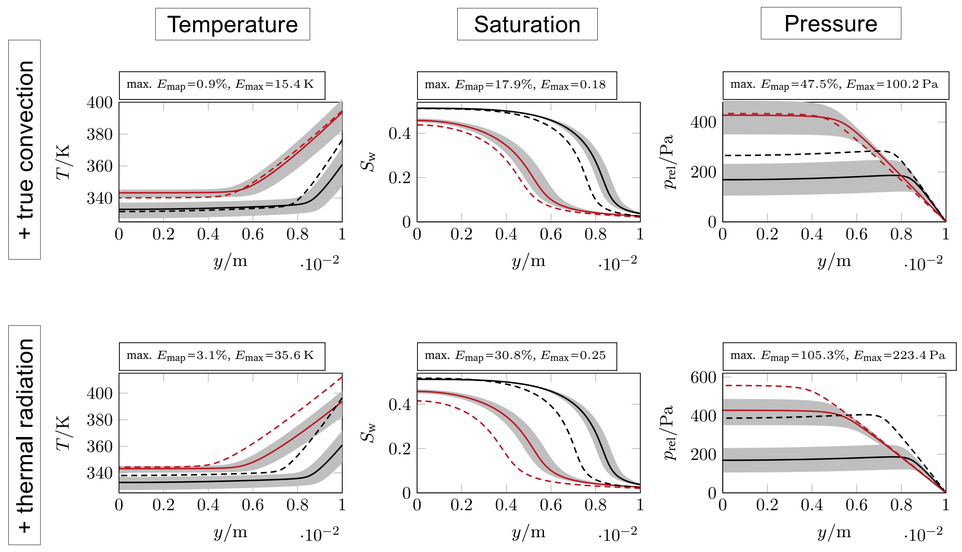


FIGURE 2. Comparison of the coupled model (dashed lines) to constant-heat-transfer-coefficient-based simulations (solid lines) at two instances in time reveals pronounced deviations.

Conjugate Simulation Setup

"The basis of accurate digital twins must be coupled simulations of process and product."

Non-isothermal, turbulent fluid flow is modeled within COMSOL® (*Non-isothermal Flow, Heat Transfer in Solids and Fluids, Turbulent Flow SST, Surface-to-Surface Radiation*).

Multi-phase heat and mass transfer and phase change effects of the hygroscopic, capillary-porous food model are implemented with the *Coefficient Form PDE* interfaces, the *Darcy's Law* fluid flow interface and numerous variable and function definitions.

TwinLab Toolbox

"TwinLab connects simulation models, data science and model-predictive control techniques in one framework."

- Synthesis of amplitude-modulated pseudo-random binary sequences for non-linear system identification
- Correlation-based efficient design of experiment on forerunner models
- Highly accurate field data replication (RMSE < 0.8 K) with augmented neural ODEs and POD base functions
- Speed-ups of the digital twin compared to real time are approximately Sp ≈ 3.6 × 10^4, with solution times of max. 0.4 s

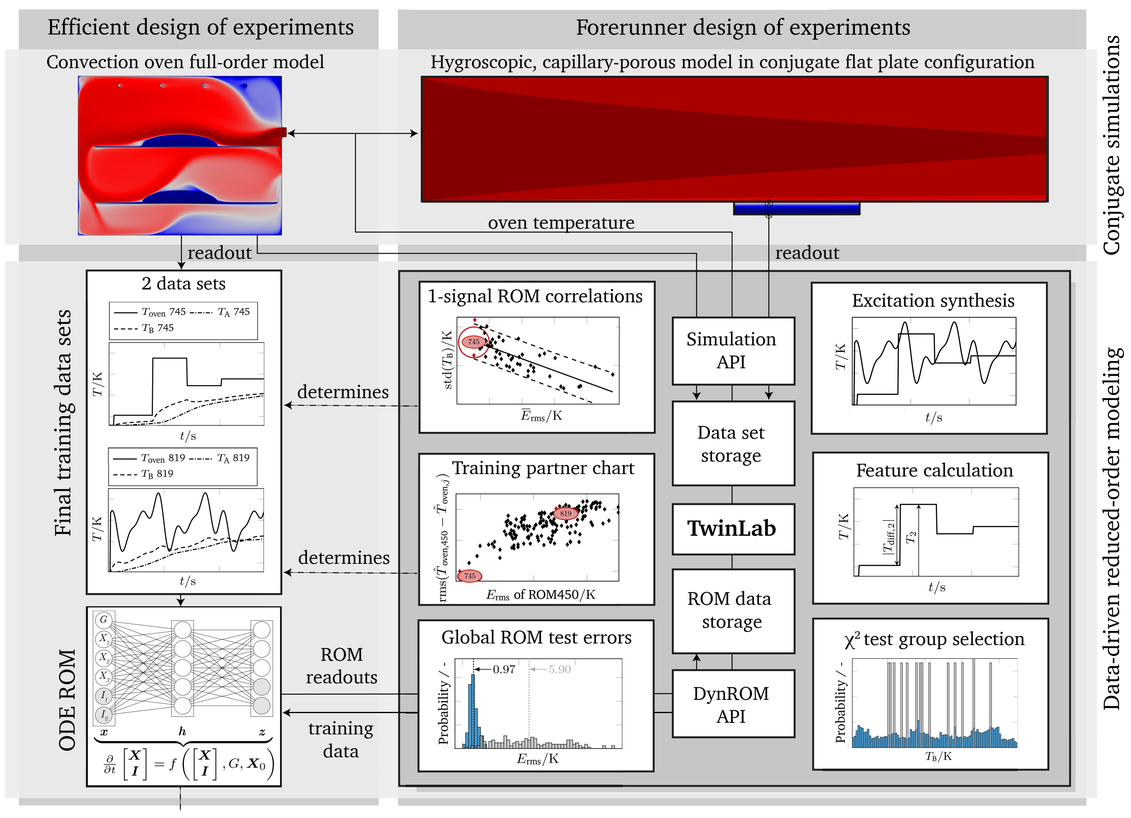


FIGURE 3. Automated training data synthesis via the COMSOL *command line interface* and *model methods* to identify correlations between global ROM test errors and training data properties.

REFERENCES

[1] M. Kannapinn, M. K. Pham, and M. Schäfer. "Physics-based digital twins for autonomous thermal food processing: efficient, non-intrusive reduced-order modeling". In: Innovative Food Science & Emerging Technologies 81 (2022), p. 103143.
[2] M. Kannapinn, Digital Twins for Autonomous Thermal Food Processing. PhD thesis, Technische Universität Darmstadt, 2023

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