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MULTI-DISCIPLINARY SIMULATION-BASED DIGITAL TWINS FOR MANUFACTURING SYSTEMS

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ABSTRACT

In recent years, digital twin solutions have been introduced into manufacturing using various engineering software, informatics and sensing technologies. These allow the capture and transfer of a near-continuous stream of data from the physical production systems and processes to virtual environments, where modelling and simulation can predict future system behaviour. These predictions are then used for decision making and control. Most commonly, digital twin solutions use data-driven models to predict the future behaviour of the system or process based on the sensor data. This presentation proposes how "simulation from first principles" can be used for digital twins in manufacturing. Simulation-based digital twins remove the need for onerous historical datasets that are required to train data-driven models. Different techniques for using multi-disciplinary simulations with these digital twins are proposed. Three simulation-based digital twins are presented, demonstrating three commercial case studies, related to pharmaceutics, fast-moving-consumer-goods, and aerospace (additive) manufacturing.

1 INTRODUCTION

In this work, the following definition for a digital twin is being adopted: "a digital twin includes a virtual representation of a considered physical asset, which generates functional outputs and has a live digital coupling to the physical asset to obtain data on the current state" (AMRC, 2020). Advances in connectivity and information technology have resulted in solutions with interconnected sensors, controllers, devices networked together with computers' industrial applications. This has enabled automated exchange of data between manufacturing systems and simulations, and providing live digital couplings for digital twins.

The virtual representation is currently typically developed using a data-driven approach. For these, developing the virtual representation starts with analysis of historical datasets, using data analytics such as machine learning. This reveals principal components and correlations between independent variables and responses. The extracted relationships are then implemented for deployment as part of the digital twin's virtual representation that generates the functional output based on the incoming state information for the physical system. The scope of these digital twins is dictated by the scope of the available datasets. This is a powerful approach and can provide highly useful predictions for the digital twin's functional output. In this work, these are referred to as "data-driven digital twins".

An alternative approach is using simulation from first principles to create the digital twin's virtual representation to avoid the need for historical datasets. These model the considered system's underlying behaviour to predict the digital twin's functional output. These simulations are based on the system's design, process and operation configurations, as well as the characteristics of raw materials and incoming parts. The functional output of the digital twin prescribes the scope and fidelity of the simulations. In this work, these are referred to as "simulation-based digital twins".

When the scope of the digital twin covers multiple disciplines, it becomes necessary to combine multiple simulations within the virtual representation. Various approaches can be adopted for these types of multi-disciplinary simulation-based digital twins. One approach is to develop a single hybrid simulations, typically combining system's simulation (discrete event simulation), operation simulations (robot simulation), and process simulations (e.g. computational fluid dynamics or thermal modelling). Hybrid simulations are developed using a single tool, for example a high-level programming and numerical computing environment. However, this quickly becomes a cumbersome approach, which requires implementation of functionality that is already available in dedicated, specialised simulation tools. Additionally, hybrid simulations are application-dedicated implementations, which obstructs re-use.

An alternative for integrating multi-disciplinary simulations within a digital twin is using simulation workflows and/or co-simulation. These techniques enable multiple domain-specific simulations to work in tandem and represent the interdependencies by exchanging inputs and outputs between the simulations. The modular nature with the stand-alone simulations offers flexibility and enables re-using these across digital twins. These also provide efficient execution with automated data handling which contributes further to re-use and reconfigurability.

2 COMMERCIAL CASE STUDIES

In this section, three commercial case studies are presented that describe how the proposed simulation-based digital twin for manufacturing platform has been deployed. The first commercial case study considers a digital twin for production of liquid personal care products. Its scope is the mixing of ingredients to produce a homogenous mixture with certain qualities (i.e. viscosity and acidity) and certain quantity (i.e. batch size). The virtual representation is a multi-disciplinary simulation workflow that includes a mathematical motor model, a mixing simulation, and a data-driven recipe correction model. The mixing simulation was replaced by a mathematical surrogate model because it was too computationally expensive for the digital twin's timeframe. Based on the state information from temperature, motor sensors (i.e. torque and speed), the digital twin then instructs the recipe correction process controller. The benefits with this digital twin are that recipe correction can be automated with easy-to-retrofit sensors.

In the second commercial case study, the simulation-based digital twin enables informed decision-making for control actions by operators. The scope is a pharmaceutical production system that forms, fills and seals blister packs for tablet products and focusses on limiting the exposure of tablets to high temperatures at blister filling, as this can be harmful to tablets quality. Operators perform control actions on takt time, forced cooling and room temperature. The multi-disciplinary workflow includes a discrete event simulation of the production system, a thermal model for the cooling of the blister, and an operation cost model. Without requiring additional sensors, it proposes feasible actions to control the blister temperature and predicts their wider impact with respect to productivity and operation costs. The feasible control actions and associated impact are presented to operators. The benefits with this digital twin are that it removes experience-based estimates by operators.

The third commercial case study uses a digital twin for adaptively optimising production schedules, and focusses on additive manufacturing production systems. The digital twin collects data from shop-floor systems such as a manufacturing execution system and enterprise resource planning software to understand the current state. The simulation workflow includes a mathematical optimisation model, a discrete event simulation of the production system and a cost model for the operation costs. The digital twin is triggered when shop-systems register events that affect the production schedule, and adaptively updates the schedule to account for the changed state. The optimisation objective function considers both productivity and production costs. The connectivity enables event-based, reactive rescheduling.

REFERENCES

The University of Sheffield, AMRC, "Untangling the Requirements of a Digital Twin," High Value Manufacturing Catapult (HVMC), Innovate UK, Sheffield, 2020.