Titre du projet : Digital Twin design methodology for automated manufacturing systems

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(Le porteur s'engage à participer et présenter son projet aux journées de la GI-EIF)
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Résumé : (200 mots)

Un jumeau numérique est une représentation numérique dynamique d'un système physique, synchronisée avec lui par un échange bidirectionnel de données. Il sert à la surveillance, à la simulation, à la prédiction et à l'aide à la décision. Il repose sur trois composantes : des flux de données multimodaux, des modèles hybrides recalibrables et des services d'aide à la décision. Les systèmes industriels sont toutefois conçus à partir de modèles hétérogènes (mécanique, électrique, automatisation, logiciel), développés indépendamment. Cette fragmentation freine l'interopérabilité. Le JN peut alors servir de cadre d'intégration pour coordonner les disciplines. Le stage vise une méthodologie fondée sur le cycle de vie, par la co-ingénierie du CPPS (systèmes de production cyber-physiques) et de son JN. Il traite trois défis:

- relier automatiquement les représentations d'un même composant (3D, schémas électriques et pneumatiques, SysML) avec 3DEXPERIENCE et CATIA Magic;
- exploiter automatiquement les modèles SysML, par exemple en les transformant en une représentation traitable en Python ;
- intégrer les transformations de produit et les flux de production au modèle système, par exemple une bouteille remplie puis bouchée.

Sujet développé :

A Digital Twin (DT) is a dynamic digital representation of a physical system, continuously synchronized with it through bidirectional data exchange. Beyond simple modelling, it enables monitoring, simulation, prediction, and decision support throughout the system lifecycle. Initially developed in critical sectors such as aerospace and energy, DTs are now at the heart of industrial digital transformation and Cyber-Physical Production Systems (CPPS). In the context of Industry 5.0, DT play a central role in the design, operation, and reconfiguration of CPPS, where equipment, software, sensors, and human operators interact.

A DT relies on the integration of three interdependent scientific components:

- **Multimodal data streams** (historical, real-time, and event-based), capturing system variability and uncertainty,
- **Computational and hybrid models** (physics-based, data-driven, reduced-order), capable of continuous recalibration via data assimilation,
- **Decision-support services** (diagnosis, prognosis, prescriptive analytics), enabling proactive and model-informed control of the physical system.

However, industrial systems are generally designed using heterogeneous models from different disciplines (mechanical, electrical, automation, and software engineering), which are often developed independently. This fragmentation limits interoperability and constitutes a major obstacle to the deployment of coherent and evolvable DT.

In this context, the DT provides an integration framework capable of bringing together this fragmented knowledge within a unified digital representation. Beyond simulation, it acts as a support for coordinating different engineering disciplines, fostering the consistency, evolution, and reconfigurability of intelligent production systems.

PROPOSED APPROACH AND INTERNSHIP CHALLENGES

The objective of the internship is to contribute to a **lifecycle-oriented methodology for DT development**, based on the **co-engineering of the CPPS and its DT**. The approach will aim to ensure consistency, traceability, and interoperability across the different engineering disciplines involved in the development of automated production systems.

In practice, a production system is described through multiple engineering views, including **mechanical, electrical, pneumatic, automation, system, and production/flow management views**. These representations are generally developed using different modelling approaches and tools, which makes it difficult to maintain consistent links between them throughout the system lifecycle. A given physical component may, for example, be represented simultaneously in a 3D model, an electrical schematic, a pneumatic schematic, and a SysML model. Similarly, the system-level representation must be able to capture not only the physical architecture but also the **production processes, product transformations, and material flows**.

This raises the need for mechanisms capable of **connecting heterogeneous representations, maintaining traceability between models, and automatically exploiting the information contained in system models**. Such mechanisms could facilitate model consistency checking, the navigation between engineering views, and the evolution of the DT as the physical system changes. The use of MBSE and SysML provides a system-level framework for structuring these relationships, while tools such as **3DEXPERIENCE and CATIA Magic** may support the integration of heterogeneous engineering representations.

The internship will investigate how heterogeneous models from mechanical, electrical, fluidic, automation, and software engineering can be decomposed, connected, and integrated into a coherent DT. The objective is to support multi-engineering simulation and co-simulation while maintaining links between system-level specifications, engineering models, and physical components.

Three complementary challenges will be addressed:

- **Interconnection of engineering views:** since the same component may appear in multiple views (mechanical, electrical, pneumatic, production/flow, and system), investigate how to automatically establish correspondences between these representations and their associated bills of materials (3D, electrical schematics, and pneumatic schematics), notably using the capabilities of **3DEXPERIENCE and CATIA Magic**.
- **Automatic exploitation of SysML models:** investigate how SysML models, particularly block diagrams, can be **automatically read and analyzed by a computer program**, for example by transforming the SysML model into a representation that can be processed using Python.
- **Integration of system and production/flow views:** investigate how to integrate **product transformations and production flows** into the system model, for example the transformation of a bottle, a cap, and water into a filled bottle, and finally into a filled and capped bottle.

The final objective is to propose a **generic and adaptable methodological framework** for integrating and exploiting the different models of an automated production system within a coherent and evolvable Digital Twin.

EXPECTED DELIVERABLES

The expected outcomes of this research internship are:

- A structured academic and industrial **literature review** on modelling methods for automated production systems, MBSE, and multi-engineering DT development.
- The **continuation and consolidation of the work initiated by two previous internships,** respectively focused on MATLAB-based modelling and simulation and on MBSE/SysML system modelling. The objective will be to deepen these developments and establish connections between representations of the same component across different engineering domains, potentially using the integration capabilities of **3DEXPERIENCE** and **CATIA Magic.**
- The **extension of the SysML model,** to provide a consistent representation of production articles and flows, and to establish links between system-level views and production/flow management views.
- The **exploration of automatic analysis and processing of SysML models,** including the transformation of model information into a machine-readable representation to support automated validation, analysis, and model exploitation.
- **Evaluate and validate the proposed methodology on a case study** representative of a CPPS. Assess its feasibility and potential for generalization to different industrial contexts. Produce a synthesis report presenting the methodology developed, the results obtained, and prospects for transfer to other applications.