Phd Proposal

Digital Twin Technology to orchestrate model based autonomous and self-adaptive systems

Autonomy and self-adaptation characterize nowadays and future systems in almost every application domain: automotive (e.g. Tesla autonomous cars), robotics (e.g. Boston Dynamics robots), manufacturing (e.g. on demand Industry 4.0 production lines).
These highly autonomous systems are very challenging to build, they need functionalities ranging from monitoring, analysis, planning, decision making to self-adaptation and self-configuration. The digital twin concept has been firstly defined and used by NASA to address the aforementioned challenges during all the lifecycle phases of spacecrafts from design, engineering, operation to disposal.
The digital twin is defined by NASA and USAF (United States Air Force) as "an integrated multi-physics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" [1]. The application cases of digital twins are mainly grouped in three domains: manufacturing, aviation and healthcare [2]. The Digital twin technology is expected to become a central capability in MBSE (Model Based Systems Engineering) because it can enable MBSE to span the full system life cycle and helps guarantee complex systems autonomy and self-adaptation from the system design phase to the operation phase [5]. More precisely, Digital twins can be exploited in:

- upfront engineering (e.g., system design and verification by simulation),
- testing (e.g., model-based system validation)
- system run time monitoring, diagnosis and self-adaptation (e.g., identify and address unpredicted and undesired behavior before they actually occurred).

The aim of this phd thesis is to leverage the digital twin technology in an existing MBSE ecosystem based on an open source eclipse project Papyrus[3] to address system run time monitoring, diagnosis and self-adaptation.
The phd candidate will investigate the following research and development questions :

- How to design a digital twin reference architecture and an API that are independent from the services that will use them. It is important to architect the digital twin for reuse in different application domains to reduce costs.
- How to link the physical asset to its virtual representation using reliable and low latency connectivity and how to efficiently monitor the physical assets and collect real time data ? New IoT (Internet of Things) technologies will be investigated in this direction.
- How to build a runtime environment for the digital representation of the assets using the Models@Runtime approach [4],
- What approaches and standards for specifying semantics are suited to ensure semantic interoperability between running assets and then automated interpretation and analysis of runtime data ?

- How to ensure self-adaptation and self-configuration capabilities in the digital twin. Stochastic optimization techniques are a potential candidate solution for self-adaptation [6].

Work Plan

1. A state of the art study of existing digital twin solutions (commercial, academic, open source and proprietary) , their strengths and drawbacks.
2. Design of a digital twin reference architecture that will leverage an existing Model based systems engineering eco-system developed in CEA List.
3. Implementation of all or a parts of the digital twin building blocks (monitoring, analysis, planning, prediction, control, etc) and experimentation on real demonstrators in the robotic and Industry 4.0 domains.

The scope of this thesis will go beyond the mere abstract theoretical framework, i.e., the successful candidate is expected to develop a software tool that will integrate the Digital Twin technology in an existing MBSE ecosystem.

References

[1] Glaessgen, E.H.; Stargel, D.S. The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles. In Proceedings of the AIAA 53rd Structures, Structural Dynamics, and Materials Conference: Digital Twin. Special Session, Honolulu, HI, USA, 23–26 April 2012.

[2] B. R. Barricelli, E. Casiraghi and D. Fogli, "A Survey on Digital Twin: Definitions, Characteristics, Applications, and Design Implications," in IEEE Access, vol. 7, pp. 167653-167671, 2019, doi: 10.1109/ACCESS.2019.2953499.

[3] Papyrus Eclipse Project, https://www.eclipse.org/papyrus/

[4] Bencomo, Nelly & France, Robert & Cheng, Betty & Aßmann, Uwe. (2014). Models@run.time: Foundations, Applications, and Roadmaps. 10.1007/978-3-319-08915-7.

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[6] Z. Coker, D. Garlan and C. L. Goues, "SASS: Self-Adaptation Using Stochastic Search," 2015 IEEE/ACM 10th International Symposium on Software Engineering for Adaptive and Self-Managing Systems, Florence, 2015, pp. 168-174, doi: 10.1109/SEAMS.2015.16.