Authoring and synchronization of the Digital Twin in virtual and augmented reality for the factory of the future

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This PhD is part of the 5GMetaverse project, which aims to prepare and promote 5G for the needs of the metaverse.

In this context, this PhD project aims to design virtual reality and augmented reality tools for authoring Digital Twin in the factory of the future. These tools should enable collaborative authoring of Digital Twin, both by augmented reality users present in industrial facilities, and by remote virtual reality users. It will also be necessary to study how to synchronize the evolution of the real environment with its Digital Twin.

This work follows on from the PhD work of:

- Cédric Fleury (defended June 2012)
  - Design models for remote collaboration in distributed virtual environment: from architecture to metaphors
  - https://theses.hal.science/tel-00765338
- Pierre Bégout (defended December 2022)
  - 3D authoring tool for the digital twin of assembly lines to augment the operator of the factory of the future
  - https://theses.hal.science/tel-04018858

The first objective of this PhD project is to facilitate the authoring of Digital Twin in Industry 4.0 by enabling several types of users to collaboratively build and update the 3D model of this Digital Twin. These users, ranging from operators directly on real production lines to engineers working remotely in a design office, will be able to use virtual and augmented reality devices to carry out this co-authoring work. Previous work has demonstrated the benefits of authoring virtual content directly in augmented reality [Lee 2005] or virtual reality [Prouzeau 2020][Chauvergne 2023]. The main challenge of this project is to offer similar or complementary interaction capabilities to these users, whatever their hardware device and their level of expertise with the technology. It could also be interesting to allow users to switch interaction devices depending on the tasks they need to perform, moving from mobile devices or standard computers to more immersive devices such as virtual or augmented reality headsets. We aim to extend our previous work [Bégout 2020][Bégout 2022] to enhance interaction with authoring tools so that it can be performed at any time and by all stakeholders, regardless of where they are and what interactive device they are using. The tools developed as part of this PhD will contribute to the Digital Twin obtained within the project, which will also be used as a support for authoring (definition of interaction zones, definition of augmentation zones, etc.).

The second objective of this PhD project is to contribute to the implementation of two-way data communication, from real to virtual and from virtual to real, for the transfer of dynamic 3D objects (meshes and point clouds). This will involve studying architectures of collaborative virtual reality and augmented reality systems [Fleury 2010] and the associated software architectures [Duval 2011]. Based on our experience in the field of collaboration for scientific visualization, we wish to address the issue of synchronizing elements of the plant in the broadest sense (including its operators) acquired dynamically and visualized in different ways. The goal is to determine the software architecture that needs to be set up to enable multiple users of the metaverse to benefit from the classic "WYSIWIS" (What You See Is What I See) of Collaborative Virtual Environments, to challenge them with the transfer of large quantities of data.

Expected skills of the PhD candidate:

- Skills in Mixed reality (Virtual Reality - Augmented Reality) required,
- Skills in Software development required,
- Skills in Unity 3D or Unreal Engine development would be highly appreciated,
- Skills in human sciences, such as knowledge in cognitive ergonomics, user studies and statistical analysis of experimental results, would also be greatly appreciated,
- Excellent writing skills in English are a mandatory.

Provisional schedule:

- **Months 1-6**: Study of the state of the art, familiarization with development tools (Unity 3D, C#), discussion with 5GMetaverse project partners about the Digital Twin's authoring needs and the architectural requirements of the system.
- **Months 7-15**: Design of interaction metaphors for a VR authoring tool for the Digital Twin of a factory, implementation of a first prototype of this tool and connection with a real Digital Twin model.
- **Months 16-18**: Extension of the system to collaborative authoring in VR and evaluation of this system on a collaborative situation.
- **Months 19-24**: Design of interaction in AR for authoring, adding the ability to modify the 3D model of the factory's Digital Twin also in AR.
- **Months 25-27**: Optimization of system architecture to enable dynamic 3D model transfers.
- **Months 28-30**: System evaluation on an asymmetrical collaborative authoring situation in VR-AR.
- **Months 30-36**: Writing of thesis manuscript and preparation of defense.

Related work:

- [Fleury 2010] Architectures and Mechanisms to efficiently Maintain Consistency in Collaborative Virtual Environments. C. Fleury, T. Duval, V. Gouranton, B. Arnaldi. In Proceedings of SEARIS 2010 (IEEE VR 2010 Workshop on Software Engineering and Architectures for Realtime Interactive Systems), p. 87-94, Waltham, 125assachusetts, USA, March 21, 2010

- [Duval 2011] PAC-C3D: A New Software Architectural Model for Designing 3D Collaborative Virtual Environments. T. Duval, C. Fleury. In Proceedings of ICAT 2011 (21th International Conference on Artificial Reality and Telexistence), p. 53-60, Osaka, Japan, November 28-30, 2011

- [Bégout 2020] WAAT: a Workstation AR Authoring Tool for Industry 4.0. P. Bégout, T. Duval, S. Kubicki, B. Charbonnier, E. Bricard. In proceedings of SALENTO AVR 2020, 7th International Conference on Augmented Reality, Virtual Reality and Computer Graphics, Lecce (online), Italy, September 7-10, 2020

- [Bégout 2022] Augmented Reality Authoring of Digital Twins: Design, Implementation and Evaluation in an Industry 4.0 Context. P. Bégout, S. Kubicki, E. Bricard, T. Duval. In in the "Exploring Synergies between the Digital Twin Paradigm and eXtended Reality" research topic of "Technologies for VR" section of Frontiers in Virtual Reality, June 2022

- [Lee 2005] Gun A. Lee, Gerard J. Kim, and Mark Billinghurst. 2005. Immersive authoring: What You eXperience Is What You Get (WYXIWYG). Commun. ACM 48, 7 (July 2005), 76–81.

- [Prouzeau 2020] Arnaud Prouzeau, Yuchen Wang, Barrett Ens, Wesley Willett, and Tim Dwyer. 2020. Corsican Twin: Authoring In Situ Augmented Reality Visualisations in Virtual Reality. In Proceedings of the International Conference on Advanced Visual Interfaces (AVI '20).

- [Chauvergne 2023] Edwige Chauvergne, Martin Hachet, and Arnaud Prouzeau. 2023. Authoring Interactive and Immersive Experiences Using Programming by Demonstration. In Proceedings of the 34th Conference on l'Interaction Humain-Machine (IHM '23).