DEVELOPMENT OF DIGITAL TWINS FROM HIGH-FIDELITY SIMULATIONS FOR HEALTHCARE APPLICATIONS

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Introduction

The approach of using in-silico models based on computer-aided engineering (CAE) to study diseases, suggest treatment strategies and predict surgical outcomes proved to be crucial in supporting the clinical staff [1]. However, the high numerical complexity and computational cost still represent a challenge with respect to the exploitation of such results. To overcome these limitations, new methods based on medical Digital Twins (DTs) are under development. DTs are virtual replicas of physical systems able to digitally replicate their behaviours providing a connection between the physical entities and the corresponding digital models [2]. In this work, we describe the techniques we use to build medical DTs and their application to two clinical cases: the drug-delivery simulation of the airway system and the determination of the effect of an exertion activity on the ascending aortic aneurysm.

Materials and Methods

The first step for building a medical DT based on simulation results involves data collection and image segmentation techniques to extract the geometry. A prerequisite is in fact having a high-fidelity model with accurate and calibrated boundary conditions able to represent the physics of interest, possibly validated with experimental data and medical images. A DT can be derived from both steady-state simulations generating static output fields (snapshots) and transient simulations providing time-varying results (scenarios). Physical parameters like pressures and flows but also geometric parameters altering the model shape can be identified. When implementing shape modifications, the mesh topology must be preserved and radial basis function (RBF) mesh morphing techniques [3] can be used.

If real-time interaction with the system is required and a compromise in terms of minor loss of accuracy can be accepted, the adoption of reduced order models (ROMs) offers the possibility to save computational time [4]. They exploit data compression techniques such as Singular Value Decomposition (SVD) or Proper Orthogonal Decomposition (POD).

Before the Digital Twin deployment, quality assessment and cross-validation of the ROM are necessary. Finally, dedicated visualization and consumption tools should be prepared to ensure the user's interaction with the twin.

Results

Two demonstrators are proposed using these techniques. The first DT is developed to monitor the effects of drug inhalation. It is built using the commercial software Ansys Static Rom Builder by combining shape parameters related to the geometry of the airways and the drug particle size with physical parameters such as the inlet flow rate.

The second application is based on Ansys Dynamic ROM Builder and derives from fluid-structure interaction analyses. By combining an accurate patient-specific model and real-time retrievable data such as blood pressure and heart rate under conditions of physical exertion, it allows the observation of clinically relevant results at the aortic wall for the study of the aneurysm growth and rupture.

Figure 1: The Digital Twins for the airway system and the thoracic aorta.

Conclusions

Results from DTs based on these techniques can be derived in almost real-time while high-fidelity simulations often require hours or days. The successful implementation of the proposed methodology suggests that it could be successfully exploited to assist the DTs generation and fruition in clinical applications.

References

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