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Editorial

Digital Twin Technology: New Frontiers for Personalized Healthcare

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1. Introduction

Rapidly evolving health digital technologies are changing modern healthcare in unprecedented ways. Health digital twin embraces most of the modern digital technologies used in medicine to produce a dynamic digital representation of the patient's anatomy, physiology, functional, and biochemical behaviour. It is achieved through computational models that are continuously updated from multimodal imaging sensors, wearable devices able to collect multiple physiological signals in real-time, laboratory and clinical data. In addition, digital twins used in combination with virtual and augmented reality and machine learning technologies will help doctors in personalised therapeutics and minimally invasive intervention procedures. Given the speed of innovation, it can be challenging to keep up with the latest technological advances. This Special Issue reports on some of the recent research efforts produced on this important topic.

2. The Present Issue

This issue collects cutting-edge research in the field of "digital twins" of organs or individuals to help doctors in the therapeutic path personalisation and minimally invasive intervention procedures. The issue includes a review paper on new detector technologies used in medical imaging and ten research papers covering important research aspects of digital twins, including finite element and computational fluid dynamics, multimodal medical image analysis and fusion, augmented reality and virtual reality, 3D virtual models, and wearable devices.

2.1. Review Paper

The authors in [1] presented a review of the recent development in detector technology for medical imaging applications. Depending on the imaging methodologies, these detectors have a different composition and are built according to different technologies. The imaging methodologies reviewed in this paper include ultrasound, optical (near-infrared spectroscopy and optical coherence tomography) and thermal imaging, magnetic resonance imaging, computed tomography, single-photon emission tomography, and positron emission tomography. For each methodology, the state of the art of detectors was described, emphasising the new technologies involved.

2.2. Research Papers

In [2], a parametric equation able to estimate the elasticity of vessel walls, non-invasively and indirectly, from information uniquely retrievable from imaging data is shown. A custom equation was iteratively refined and tuned from the simulations of a wide range of different vessel models, leading to the definition of an indirect method able to estimate the elastic modulus E of a vessel wall. This original formulation was demonstrated

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to significantly increase the reliability of the estimated E value for a vessel wall, with a mean percentage error of 9.3% with respect to the reference values.

A medical digital twin pipeline is implemented in [3] based on reduced order modelling to study the haemodynamic effects in modified Blalock–Taussig Shunt morphology in the infant. The proposed approach encourages the investigation of significant haemodynamic features such as velocity, pressure, and wall shear stress as a function of the shunt's morphology in real time. The adoption of reduced models turns out to be a promising path with the potential to support patient-specific preoperative planning.

The authors in [4] developed a semi-automatic tool for minimally invasive aortic valve replacement to support the decision to perform right anterior mini-thoracotomy. The developed tool allows to extract parameters of surgical interest and to generate a view of the anatomical region in 3D space.

In [5], the authors exploit a digital twin of coronary stenting that can reliably mimic the patient-specific clinical reality to improve individual treatments. It implements a simple, robust and effective computational method to obtain a good compromise between the accuracy of the description of physical phenomena and computational costs. The finite element model was generated through a 3D reconstruction based on the clinical imaging coronary optical coherence tomography and angiography acquired on the pre-treatment patient. From a mechanical point of view, the coronary wall was described with a suitable phenomenological model, which is consistent with more complex constitutive approaches and accounts for the in vivo pressurisation and axial pre-stretch. The effectiveness of this artery modelling method was tested by reproducing in silico the stenting procedures of two clinical cases and comparing the computational results with the in vivo lumen area of the stented vessel.

New hardware solutions in medical imaging and their benefit to organ-specific applications are discussed in [6]. The authors compare two SPECT systems, one dedicated to cardiovascular studies and one general-purpose, to evaluate the advantages and the weakness of their use in cardiac imaging. The two scanners exploit the potential of the latest generation CZT detectors, but the spatial arrangement of the detectors and collimators differs. An overall comparison of the systems was performed using a standard NEMA phantom.

In [7], the authors create a generative adversarial network for the generation of synthetic data of lung cancer patients as a tool to avoid the very delicate issue of the anonymisation process to maintain patients' privacy and data availability, especially in some health domains like lung cancer treatment. Generated synthetic patients are validated using both statistical methods, as well as by oncologists using the indirect mortality rate obtained for patients in different stages.

In [8], authors investigated the feasibility of digital, 3D patient-specific models for teaching cardiac morphology of patients with congenital heart disease. A virtual reality application containing a set of patient-specific models was developed in-house. The level of acceptance was tested among clinical professionals from a diverse range of specialities, with a high level of acceptance amongst clinical specialists when used as an effective aid for learning congenital heart disease.

In [9], an insight into biological microstructures using a combination of numerical simulation and an optical set-up based on small angle light scattering (SALS) approach is presented. It is proposed to address the mechanical features responsible for tissue pathologies in blood vessels. The numerical results were validated with the optical setup used for the characterisation of fibrous samples from 3D-printed specimens with different fibre architectures. Semi-quantitative information about the tissue anisotropy was successfully gathered by analysing the scattered light spot. Moreover, the numerical results revealed a remarkable coherence with the experimental data, both in terms of mean orientation and dispersion of fibres.

In [10], the authors developed an experimental bench test for synchronised small-angle light scattering and biaxial traction acquisition apparatus. It allows us to gain insights into the microstructural modifications of mechanical properties of biological soft tissues to improve mechanical constitutive modelling. Even if the proposed technique was designed for mechano-biological analysis for soft biological tissues, its customizability allows the usage in other biomedical fields, such as vascular grafts and cardiovascular valve prostheses.

The authors in [11] propose a novel open-source wearable IoT-like modular and fully open-source platform to synchronously acquire and process multiple physiological signals in real-time. The platform was tested on 15 subjects exposed to rest and stressful sessions based on the Stroop Color and Word Test, showing very good computational performance for data streaming, remote storing, and real-time processing.

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