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Digital Twins, history, metrics and future directions

Juan J. Nieto

[1] Galician Centre for Mathematical Research and Technology (CITMAga), Santiago de Compostela 15782, Spain
[2] Department of Statistics, Mathematical Analysis and Optimization University of Santiago de Compostela 15782, Spain

* Correspondence author; E-mail: juanjose.nieto.roig@usc.es.

Abstract: We present the current state of the Digital Twin technology. We give some historical notes, the strengths and weaknesses, the evolution of the publications on the topic and some future perspectives.

Keywords: Digital Twin; real world system; history; metrics; Digital Twin technology

1. Introduction

The mere concept of Digital Twin is still in flux. Different approaches are possible and variations from area to area appear and it is a real danger to reject it as just hype.

Depending on the subject distinct paths are possible, but it can be introduced as an evolving digital portrait of the historical and present behavior of a real object or real process contributing to optimize the execution of the real process. It is not a computational model or a virtual duplicate. A Digital twin is, in other words, a digital version representing its physical counterpart which interacting in a continuous way. Definitively it is not a mathematical model [1]. The name comes from a Roadmap report by John Vickers of NASA in 2010. There the author's purpose was to improve the physical model simulation of spacecraft. We refer to the recent Handbook of Digital Twins [2] for details on these aspects.

A Digital Twin concerns a real world system, a digital duplicate of some aspects or behavior of the real system, and data gathered on the system interacting between both.

We give a general overview on the vast area of Digital Twins (DTs). It is different in every area of knowledge and technology and some directions are indicated in the references depending on the fields: medicine, engineering, mathematics, industry, mechatronics, robotics, etc.

2. History

We could say, paraphrasing the character Humpty Dumpty in the book titled Alice's Adventures Through the Looking Glass of L. Carroll, "When I use the term Digital Twin, it means just what I choose it to mean".

Our main purpose is to give an historical context and citation metrics to reveal the revolution of Digital Twin technology.

For the best part of Digital Twin, the data one can collect will be assembled by measurement. DTs are as a result of potential interest to metrology as a valuable tool. Hence metrology is of vital importance to Digital Twins to ensure that the data used in indeed reliable [3].

The three main ingredients of Digital Twins technology are data acquisition, data modelling and data application. Digital Twin uses different technologies, as Internet of Things, Cloud Computing, Artificial Intelligence or Extended Reality, to collect and store real-time data, get information to provide insights, and, of course, create a digital depiction of a concrete physical item, device, object or system.

The applications range from product design to clinical research, or from drug development to aviation industry.

3. Strengths and weaknesses of the Digital Twins Technology

Some known advantages of Digital twins are the predictive maintenance and optimization, the possibility of product development, real-time monitoring of a system and decision support. Digital Twin technology also enhances risk management and allows institutions to predict potential safety issues or system vulnerabilities.

Also, by simulating different scenarios, it is possible to identify the most adequate strategies. Digital Twins provide a safe and controlled environment for testing new methods or ideas, but without the risks and costs associated with physical experiments.

On the contrary some cons of the Digital Twin are the complexity of its implementation and the high initial investment, both in knowledge and money, and security concerns relative to the data. The integration of existing systems entails relevant challenges for any organization. The complexity in data management and analysis is also a crucial question. The maintenance and updates of the Digital Twin is an aspect to have in mind. The technological dependency is an important point to consider and contingence plans should be implemented to mitigate failure risks.

Finally, regulatory and ethical issues have to be considered.

4. Metrics

The number of articles on (or using) Digital Twins has growth exponentially in the last years as revealed by Figure 1 and according to the data of the database Scopus in June, 2024. The most cited article is of 2019 [4] and it is on the state-of-the-art of Digital Twin in Industry.

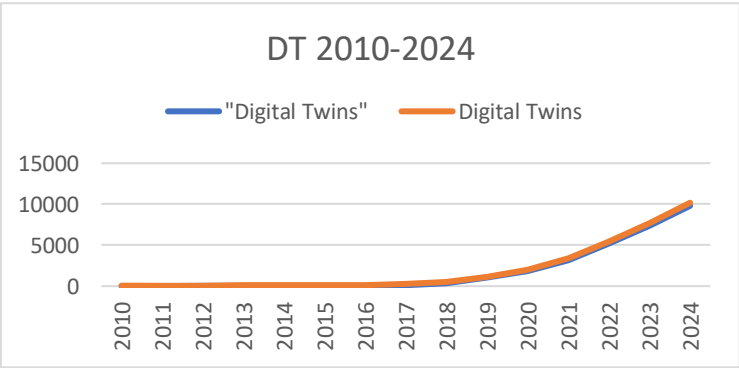

Figure 1. Number of works on DTs during the indicated years. The exponential growth is evident.

5. Future directions

Expectations are increasing in relation to the potential of Digital Twins to change scientific research, technological and industrial practices, and many characteristics of quotidian life. The synergies between Digital Twins, Artificial Intelligence and Machine Learning will generate new technologies and scientific approaches to real world processes ranging from personalized medical decision-making to more efficient engineering processes and, of course, in accelerating scientific discovery and revolutionizing technologies. Some aspects absolutely necessary to address are validation, verification and, of course, the quantification of uncertainty inherent to digital twins.

What is the potentiality of integrating Digital Twin capabilities with virtual reality technology? Also, the interconnection with the Metaverse, Blockchain and Artificial Intelligence will be unpredictable.

How does Quantum Information will contribute to the evolution, development, advancement and implementation of Digital Twins and Digital Twin Technology?

We recommend the report of the National Academies of Sciences, Engineering, and Medicine [5] to consider some demands, open needs and foundational difficulties, ideas and gaps to overcome in order to advance Digital Twins and the associated technology.

To mention just a couple of Digital Twins subjects, we indicate the case of the COVID-19 pandemic [6] to implement control measures (Figure 2), the Digital Twin corresponding to a patient's tumor cell population [7] and a new approach for vehicle dynamics control [8].

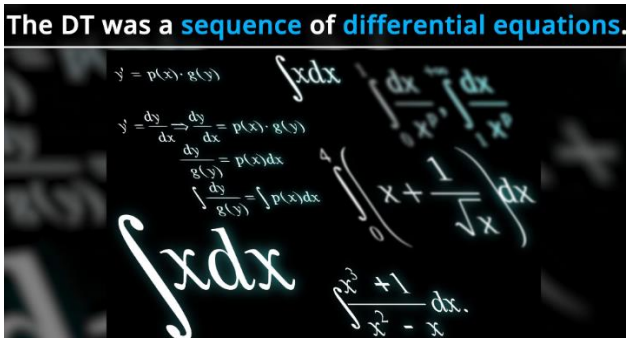

Figure 2. The use of mathematical tools in Digital Twins.

In a systematic future review, we will provide further details so that readers can appreciate different Digital Twin technologies at different fields. A bibliometric analysis on the state of Digital Twin development will be performed in order to understand the current status of research in the huge area of Digital Twin, and to analyze the research progress and evolutionary trends in this field.

Also, the key challenges and future directions necessary for a deeper development of Digital Twins in contemporary research and industry will be addressed in more detail.

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