Digital Twin Applications: A review

Andrés E. Campos-Ferreira, Jorge de J. Lozoya-Santos, Adriana Vargas-Martínez, Ricardo Ramírez Mendoza, Rubén Morales-Menéndez

Tecnologico de Monterrey, School of Engineering and Science, Monterrey, NL Mexico.
e-mail: A01420570@itesm.mx, {jorge.lozoya, adriana.vargas.mtz, ricardo.ramirez, rmm}@tec.mx

Abstract: The digital twin is a comprehensive representation of a product or process into a digital world; it plays a vital role in the product lifecycle and helps to the horizontal integration of the production process. Digital Twin is one of the most promising technologies for system simulation and monitoring. Nevertheless, the concept is relatively new and has different conceptions and applications in the literature. In this work, a review of the State of the Art on principal scientific databases is presented. Besides, a brief classification regarding the main applications found are provided and a proof of concept based on a vehicle chassis.

Keywords: Digital twin, State-of-the-Art, Cyber-physical systems, Industry 4.0.

1. INTRODUCTION

With the advances in technology, industry and companies want to supervise their products or processes. The Industry 4.0 philosophy is driving processes and products to a digital era. Some technologies like *Big Data, Digital Twin (DT) and Cyber-Physical Systems* are used to improve the competitiveness and productivity. *Industry 4.0* describes the integration of all value-adding business divisions and of the entire value-added chain with the aid of digitalization, Rodič (2017). The use of new virtual technologies is developing the industry competitiveness and productivity at exponential rate.

Haag and Anderl (2018), define DT on a simple form as a representation of a product or process into a digital world. The DT trend focuses on creating a corresponding digital representation of the operations of physical objects. In the context of *Industry 4.0*, David Cearley (2018), considers the DT, as one of the top ten technology strategic trends. In Figure 1 can be observed the hype cycle of emerging technologies, on it the DT is located at the peak of the expectations, but to reach its maturity requires further researches, developments and technology validations.

DT may be as simple as a dashboard with critical performance indicators (KPI), such as temperature, heart rate, vibration, or highly sophisticated incorporating input from many sensors and external data. This allows the DT to perform active participation from the design to the functional stage on each product or process. This work will focus on smart products and smart processes.

This document is structured as follows. In Section 2 state of the art is reviewed. In Section 3 is presented a proof of concept for a DT. Finally, the conclusions are in section 4.

2. LITERATURE REVIEW

A search was done to find the most relevant information published since 1990. The research found a total of 644 publications. The number of publications has been growing since 2014 on almost an exponential way, indicating DT is becoming a *hot* topic in the scientific community.

Figure 2 shows the generated documents in the last 5 years. The significant percentage of the publications focuses on the engineering area (manufacturing, robotics, product development) and in the computer science area (Simulations, architecture validation, communication, analytics).

2.1 Emerging technology

According to Schleich et al. (2017) the first appearance of DT was on the *NASA*'s Apollo program. A DT was defined as "An integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin", Negri et al. (2017). In this definition, *NASA* wanted to reproduce the life of its vehicles into integrated models based on

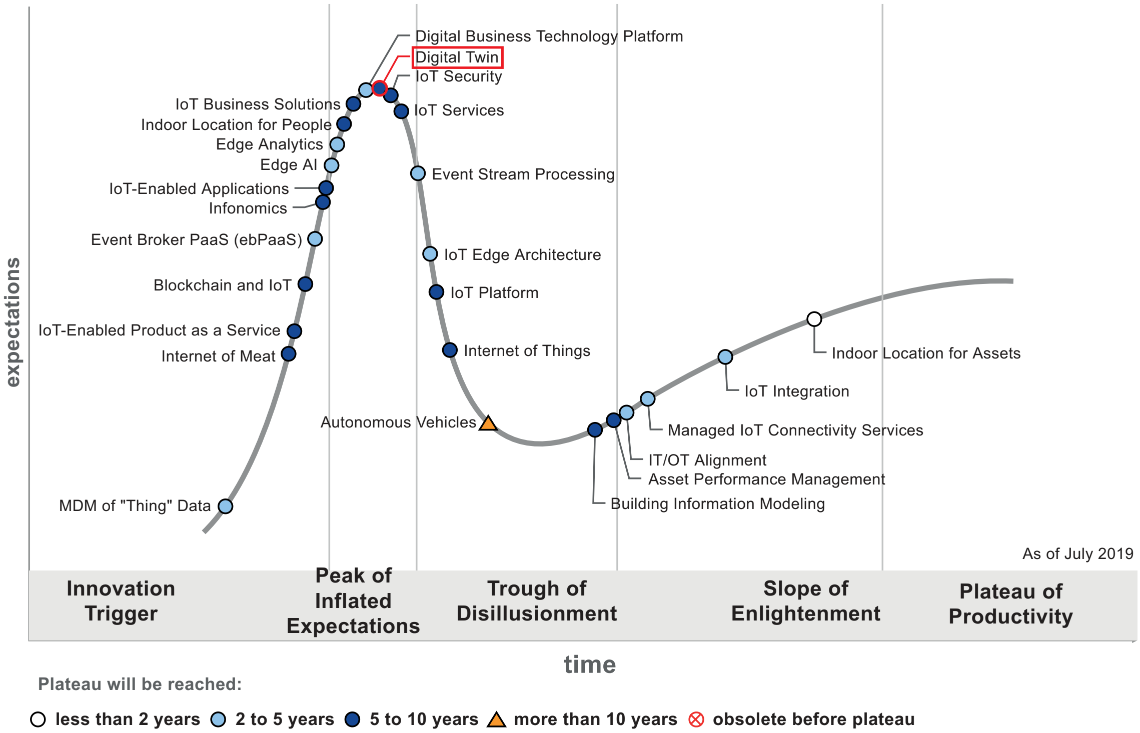

Fig. 1. Hype-Cycle for Emerging technologies from Gartner, Inc., Walker (2018)

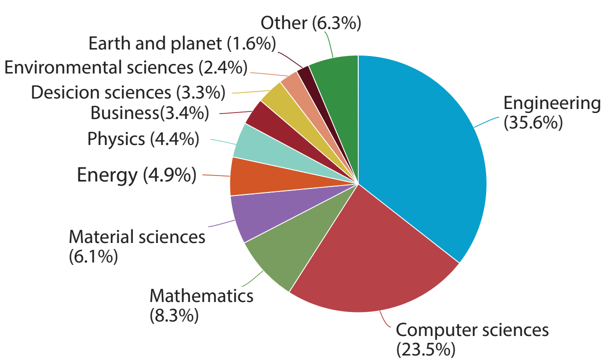

Fig. 2. Main areas of publications from 2014-2019

statistical methods, and sensors data.

With the evolution of technologies and the digitalization, DT concept has had several conceptualizations. Tao et al. (2018) claim DT is composed of a physical product, virtual product, and connected data that ties physical and virtual product. Luo et al. (2018) DT consist of a framework composed of a physical space, a digital space and a connection layer. In addition, Qi et al. (2018) create high-fidelity virtual models for physical objects in digital way to simulate their behaviors.

The DT trending technology is deeply developed in the engineering area,Tao and Rossman have the most publications regarding DT, on their work, have presented a classification and established the DT impact on manufacturing, production and simulation, Tao et al. (2018). Also, they have presented comparison between the emerging technologies such as Big Data, Qi and Tao (2018). On the other hand, Rossman has focused its efforts on developing simulation and Experimental Digital Twins *(EDT)* in Schluse et al. (2018), in Schluse et al. (2017) and Dahmen and Rossmann (2018).

According to the research, the found articles regarding the DT could be classified as:

Depending on the application and technology available, each DT proposed in literature had different architecture. In its work Schluse et al. (2018), proposes EDT as technical simulation assets, with the purpose of integrating different model components to simulate nearly any aspect of a complex system.

Schroeder et al. (2016), found that all the data generated on a DT is exchanged between different systems with no standard communication protocols, then proposes the use of software to allow interconnection of the different DT subsystems.

Haag and Anderl (2018) did not find validation in literature. Then successfully developed a cyber-physical bending beam to validate the concept and functionality of a

Table 1. DT papers classification

Classification	Description	Authors
Proposals	The author makes a proposal of a new definition or possible DT architectures.	Tao et al. (2018) Rodič (2017) Parrot (2018) Tharma et al. (2018) Zheng et al. (2018)
Simulations	In these works a simulation is done in order to validate a DT model.	Rodič (2017) Schluse et al. (2018) Vachálek et al. (2017) Yang et al. (2017)
Case of study	The authors validate the model through a set of experimentations and sometimes support its results with simulation as well.	Luo et al. (2018) Haag and Anderl (2018) Zheng et al. (2018)

DT. As was previously stated, the *DT* is an emerging technology, but does not present a defined structure. The *DT* architecture is presented in Figure 3.

- *Communication interface:* Help to transfer information from the sensor to the integration function.
- *Software modelling:* The computer program CAD/CAE used to build simulations of objects or systems.
- *Human-Machine Interface (HMI):* Consists of software and hardware that translate inputs to signals for the machine to control.
- *Digital twin services:* Area of interest on which the *DT* will focus results. Could be: Financial, logistics, training, maintenance, production, etc.
- *Analytics:* Process of inspecting, transforming and modeling data with the purpose to find useful information and present it to support decision-making.
- *Big data:* High-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making.
- *Edge processing:* Connection of sensors and process history easily. Translates proprietary protocols to understandable data formats and reduces network communications.
- *Edge security:* The most common security measurements are firewalls, encryption, device certifications, etc.
- *Sensors:* Device or module whose purpose is detect variations in its environment of some physical characteristic. It sends the information to another device.
- *Actuators:* Component responsible for moving or controlling a mechanism.
- *Vertical integration:* Arrangement of the supply chain on an enterprise.

In Table 2 is presented a classification done with the most relevant works found, taking into account the structure presented by Parrot (2018).

A *DT* in manufacture offers the capacity to simulate and improve the production system. It includes the logistics to the optimization for manufacturing process for a single piece or an assembly. Most of the papers found are related to the improvement of manufacturing processes. Most of the *DT* proposed are simulation-based as in Rodič (2017), Parrot (2018), Vachálek et al. (2017). The authors focus on the way to simulate a process to improve efficiency and predict process behaviors.

The *DT* could be employed for product design on a more efficient manner. Its ability to simulate and model the behavior of physical objects helps to the designer to improve its products. In Tao et al. (2018), the *DT* helps to enhance the design of a bicycle-based on the in-build feedback sensors to the designers, users and the sellers. Also, Tharma et al. (2018) propose the use of a *DT* for the design of wiring harness of a car taking advantage from its capability to simulate different conditions and reduce the possible designs based on the design of the rest of the vehicles and the data obtained from vehicles already on the field.

3. CASE OF STUDY

A proof of concept of a service-oriented *DT* for a vehicle chassis with a low-cost instrumentation set is presented. The purpose is to illustrate an example of a real system modelled based on the *DT* concept.

The experiment consists of calculating the stress generated by driving on a vehicle frame, then is modeled over a digital representation on the computer for the user analysis. The calculations use the data captured from the smartphone's sensors (accelerations, vibrations, speed, and position).

The vehicle for the experimentation is a Hyundai Verna model 2004. The data was collected by a Motorola MotoG4 Plus located at the car floor and Samsung Galaxy S7 Edge located at the windshield. In table 3 are listed the sensors from the smartphones and its main parameters.
The vehicle dynamics were retrieved by a smartphone application. The app is called AndroSensor (version 1.9.6.3) and senses acceleration and angular speed on the X, Y, Z-axis of the device. Then, the data was processed by Matlab and then compared with the reference data from the simulated in CarSim. Then, a finite element analysis was assessed and the results deployed. For the purpose of the validation, a bumper event will be evaluated and compared with a bumper event simulation in CarSim software.

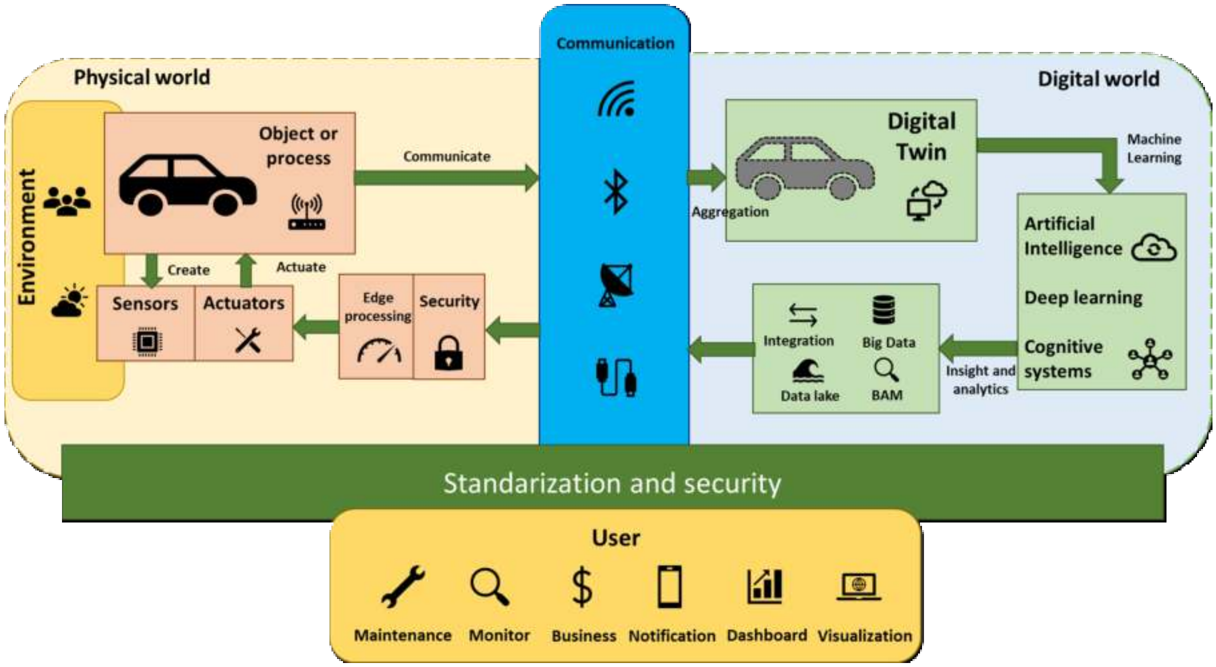

Fig. 3. *DT* architecture

Table 2. DT applications comparison

Reference	Rodič (2017)	Tao et al. (2018)	Schluse et al. (2018)	Rodič (2017)	Luo et al. (2018)	Rodič (2017)	Haag and Anderl (2018)	Parrot (2018)	Vachálek et al. (2017)	Tharma et al. (2018)
Field	Logistics	Design	Robotics	Manufacturing	Manufacturing	Manufacturing	Manufacturing	Manufacturing	Manufacturing	Product
Area of application	Planning	Design	Experimental	Production	Production	Modeling	Experiment	Process	Experiment	Product
Model	Inventory system	Bicycle	Robotic arm	SME	CNC machine	SME	Beam bending machine	DT model	Production line	Wiring harness of a car
Objective	reduce logistics risks	design	improve process	Improve production	improve product	Model enterprise	Design	Model proposal	Improve process	Design
Communication interface	custom software	Network (app)	Simulated	wireless	OPC UA	Anylogic	MQTT protocol	Wireless/wired	OPC	Not mentioned
Edge processing	real-time	N/A	real-time monitoring	N/A	real-time monitoring	N/A	Soft time analysis	Easy and fast connection	Real-time	Not mentioned
Software	SIMIO	N/A	Matlab	commercial proposed	Modelica	Java, ABM and DES	IOT platform	N/A	Plant simulation (Siemens)	KBL
HMI	SIMIO interface	N/A	FMI	comercial HMI	Mworks interface	Anylogic	IOT platform	Notifications/DS	Dashboards	Custom
Analytics	SIMIO adv. Analytics	Custom	Robot control	commercial	Artificial neural network	Custom model with java	FEM	IA/Cognitive engines/hybrid model	Genetic algorithm	Custom
Big data	Generic database	Custom database	Not used	commercial	Custom expert system	Middleware	N/A	Data insertion/Data lake/BAM	N/A	Not mentioned
Users	logistic's user	Buyers, designers, sales	Technician	process engineer	Mechanical, electrical and hydraulic	Designer	Anyone with internet acces	Depending on application	Process engineer	Development
Sensors	N/A	in-build	Camera	Camera, tracking	Vibration and temperature	N/A	Linear sensor	pressure, temperature, flow, etc	Position	Tracking, fuses
Actuators	N/A	N/A	Motors	Personnel, machines	Machine cutting tool	N/A	Load cell	hydraulic, electrical, mechanical, etc.	Pneumatic	N/A

Table 3. DT applications comparison

	Sensor	Model	Range	Sensitivity
MotoG4	Accelerometer	BMA150	-2 to 2 [g]	3.9 [mg]
	Gyroscope	BMG160	+/- 250 [°/s]	7.62 [m°/s]
Galaxy S7	Accelerometer	LSM6DS3	-4 to 4 [g]	0.122 [mg]
	Gyroscope	LSM6DS3	+/- 250 [°/s]	8.75 [m°/s]

Figure 4 shows a comparison of the 3 signals of the bump event corresponding to acceleration on z-axis. As it can be seen, the response of the signals is similar around second 9 of the test.

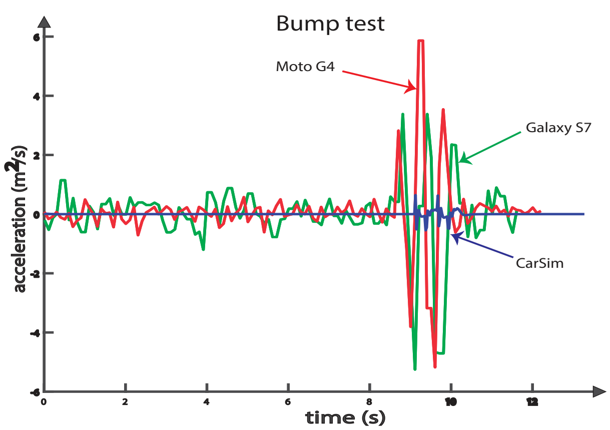

Fig. 4. Experimental and simulation data comparison

After the experimentation, the resulting vertical forces from the simulation were used to make the stress simulation. Figure 5 shows the analysis result, where can be seen the deformation caused by the bumper. It is caused by the vertical forces applied on each wheel provoking a deformation mainly on the car body center.

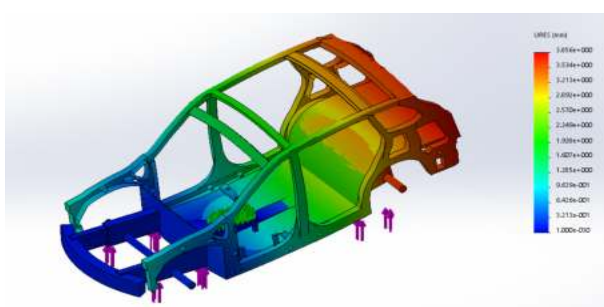

Fig. 5. Simulation results on SolidWorks

4. CONCLUSION

This review helps to understand the way of developing of *DT*. The connection between the physical world and the digital world have been a dream for the last decades and now it is a tangible proposal to monitor and modify physical objects from virtual reference. Some companies have begun to introduce *DT* into the market as a promising tool for the improvement of systems and products.

This is a very promising enabling technology with infinite possibilities, because of its nature of relating any physical object with a virtual one. Nevertheless, because of this is a very recent technology, must have more researches to validate and normalize its structure as well as its definition. From the literature review a significant advance can be seen on the manufacturing area, because of the rapidly implementation of other enabling technologies (like Internet of Things, Smart Sensors or Cloud Computing) permit the *DT* implementation. Other authors are focused on devise modelling strategies using *DT* to improve the design and control of systems, as well as detecting failures on designs.

The *DT* case of study devised for this work is an off-line *DT* with the only purpose to illustrate the *DT* paradigm. Despite is a fundamental example, it exemplifies how a physical object can be modelled and studied by generating a set of data that describes its actual state and properties. With the use of continuous data collecting, some machine learning algorithms and the correct analysis of data, a *DT* could be a very powerful tool that can have a significant impact on industry, diagnosis and failure detection, modelling and design of products.

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