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Digital Twin: An Introduction

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Abstract A digital twin is the digital replica of a physical process, person, place, system or device that mirrors the actual process and has full knowledge of its historical performance. The digital copy is continually connected to the physical object(s) and updates itself to reflect real-world changes. The digital twin of any device/system is a working model of all components integrated and mapped together using physical data, virtual data, and interaction data between them to make a fully functional replica of the device/system. Digital twin is at the forefront of the Industry 4.0 revolution. This paper presents an introduction to digital twin.

Keywords digitalization, digital twin, manufacturing

Introduction

Several processes and solutions such as manufacturing are becoming increasingly digital. Today, digitalization has become a consensus, especially digital twin, precise virtual copies of systems. Digitalization is becoming one of the main drivers of innovation in all sectors. *Industries in virtually all market sectors are facing the reality of digital transformation.* The digitalization process is greatly accelerating due to the emergence of new technologies such as Internet of things (IoT), cloud computing, big data, and artificial intelligence [1]. Digital twin represents one form of digital transformation, as illustrated in Figure 1 [2]. It is regarded the next generation of digitalization for decision making support.

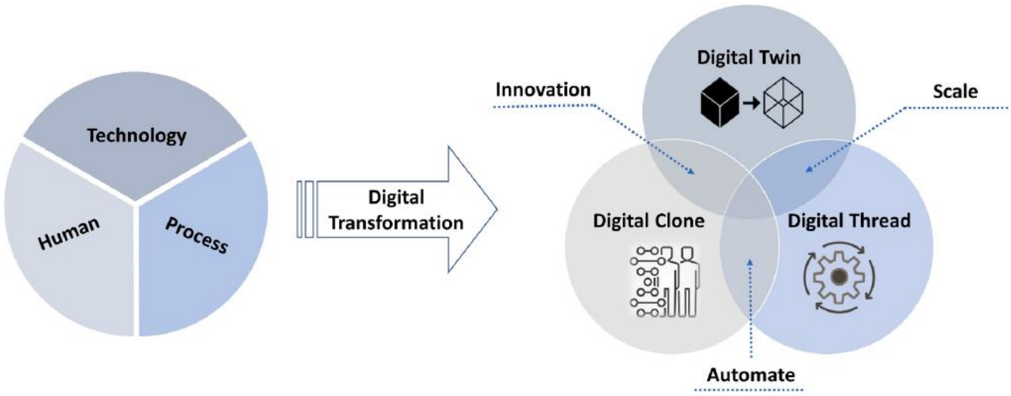

Figure 1: Digital twins as part of digital transformation [2]

Digital twin (DT) is an emerging technology to achieve physical–virtual convergence. Digital twin refers to a digital replica of potential and actual physical assets (physical twin), processes, people, places, systems, and devices that can be used for various purposes. Figure 2 shows the conceptual model of a digital twin [3].

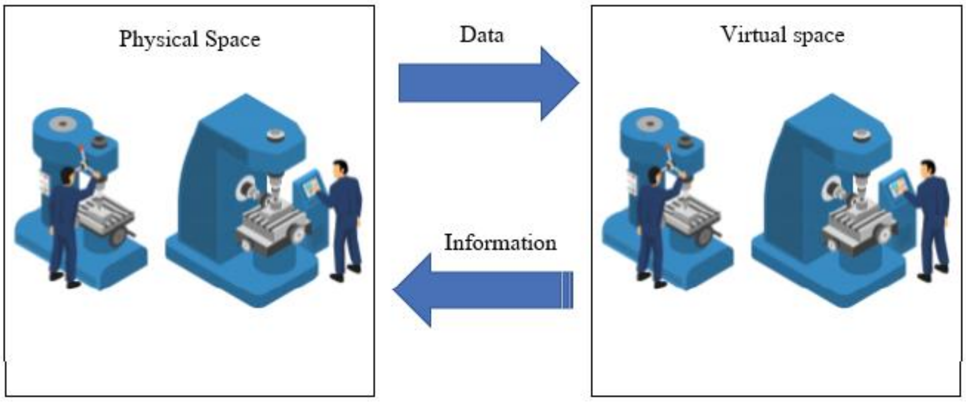

Figure 2: Conceptual model of a digital twin [3]

A digital twin continuously learns and updates itself from multiple sources to represent its near real-time status.
Digital twin (DT) is a realistic model of the current state of the process and their own behavior in interaction with their environment in the real world. For the industry, DT is regarded as a combination of an academic vision of coexistence of digital and physical world. Rapid progress in industry 4.0 concept has facilitated the growth of DT, particularly in the manufacturing industry. DT integrates multiple disciplines such as computer graphics, image processing, 3-D rendering, graphics engine, mechanics, data analysis, artificial intelligence, machine learning, etc. Implementing digital twin is a complex, long-drawn process, which requires multiple technologies and tools to work together [4].

Concept of Digital Twin

The concept of the digital twin was introduced in 2002 by Michael Grieves of Florida Institute of Technology. He applied the concept in manufacturing and proposed the digital twin as the conceptual model underlying product lifecycle management (PLM). The concept was being practiced since the 1960s by NASA. The concept of digital twin consists of three distinct parts: the physical product, the digital/virtual product, and connections between the two products [5].

A digital twin is much as it sounds: creating a digital duplicate of the physical entity.

It has two sides, one pertaining to a physical device and the other to a digital rendition of this device. DT is a real time digital replica of a physical device using 3D modeling and sensors. The DT is an emerging paradigm focusing on an enterprise asset such as a system, product or process. Its core goal is to virtually represent this asset as close to reality as possible. A digital twin may exist before its physical counterpart is made. Technologies enabling DT include AI, IoT, 5G, virtual reality, augmented reality, wearables, and cloud computing. Realizing the full potential of DTs requires a convergence of these technologies. Digital twins integrate AI, IoT, machine learning, and software analytics with spatial network graph to create living digital simulation models that change as their physical counterparts change.

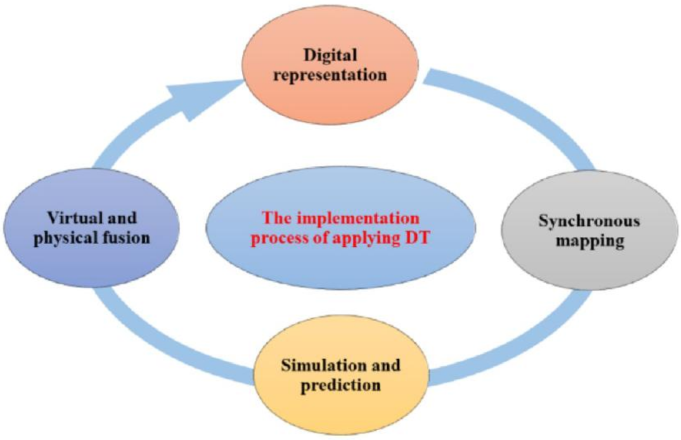

Figure 3: The implementation process of applying DT [6]

The three main pillars of the digital twin technology are visualization, emulation, and simulation. The foundation of DT is the physical world, which may consist of devices/products, physical systems, process, or an organization. Service is an essential component of DT in view of the paradigm of everything-as-a-service. DT-related services include application service, resource service, knowledge service, and platform service. The process of implementing DT can be divided into four steps: digital representation, synchronous mapping, simulation and prediction, and virtual and physical fusion, as depicted in Figure 3 [6].

There are numerous requirements to describe "digital twin." To be considered a digital twin, the model must have some specific characteristics such as [7]:

(1) Data is the carrier of information and the key driver of DT. Real-time data is important for knowing the status of the product. Data-driven digital twin can perceive, respond, and adapt to the changing environment.

(2) Integration of the different nodes is essential for creating valuable data. Sensors communicate the data to the digital world through integration technology between the physical world and the digital world, and vice versa.

(3) Scalability (ability to analyze different scales of information);

(4) Interoperability (ability to convert, match and establish equivalence between representation models);

(5) Expansibility (ability to integrate models);

(6) Fidelity (ability to conform to the physical model); the core of any DT is a high-fidelity virtual model.

(7) Connectivity that indicates the level of communication with its physical counterpart; connectivity by design through IoT which is a paradigm for ubiquitous connectivity. Connect the products/services to a central location with streaming, big data, in-memory, and analytic capabilities to capture sensor data and enrich it with business and contextual data.

These are the most frequent requirements of digital twins.

Applications

The digital twin is disrupting the entire product lifecycle management (PLM), from design, to manufacturing to service and operations. DT applications can be found in manufacturing, smart city, business, retail, construction, healthcare, agriculture, cargo shipping, drilling platform, automobile, aerospace, sports, military, education, etc. With these applications, our lives can be improved using DT. We now consider ten popular areas of applications of digital twins [8,9].

- *Manufacturing*: Manufacturing companies are highly disrupted by digital twins. Digital twins are being used to optimize the operation and maintenance of physical assets, systems, and manufacturing processes. The physical manufacturing objects are virtualized and represented as digital twin models (avatars) seamlessly and closely integrated in both the physical and cyber spaces. The data gathered from the physical manufacturing process is continuously communicated and collected by the digital twin, which drive the future of the manufacturing industry. DT has the potential to achieve smart or intelligent manufacturing. Current advancement in the Internet of things (IoT), cyber physical system (CPS), and big data continuously reshapes modern manufacturing, which requires high speed, precision and flexibility, equipment reliability and operational safety [10]. The future of manufacturing drives on the following four aspects: modularity, autonomy, connectivity, and digital twin.
- *Healthcare:* This is another industry that is recognized as being disrupted by the digital twin technology. This is taking a more data-driven approach to healthcare. The digital twin allows individual's records to be compared to the population in order to find patterns easily. The major benefit of the digital twin is that it enables healthcare to be tailored to individual patients. However, the emergence of the digital twin in healthcare also brings some downsides. The digital twin may lead to inequality, as the technology might not be accessible for everyone by widening the gap between the rich and poor.
- *Automotive:* As automobiles become progressively integrated with digital technology, the ability to replicate every detail becomes necessary. Digital twins in the automobile industry, as notably

demonstrated by Tesla, are implemented by using existing data in order to facilitate processes and reduce marginal costs. An example of digital twin technology in the automotive industry is where automotive engineers use digital twin technology in combination with the firm's analytical tool in order to analyze how a specific car is driven.

- *Retail*: The implementation of this concept of a digital twin plays a key role in augmenting the retail customer experience. With new technology capabilities, flexibility, agility, and lower cost, companies can create a digital twin with lower capital investment and shorter time to value than ever before.
- ***Smart Cities***: Urban areas or cities are becoming increasingly smarter these days because they can use the data generated from a wide variety of activities in the city to improve the mobility, environment, living standards and governance of the city. The application of digital twins within a smart city is increasing due to rapid developments in connectivity through IoT. A digital twin of cities is a possibility which could make search engines capable of finding anything in the physical world. DT can prove highly advantageous for analyzing the different forms of transport and pedestrian movement patterns. With the help of augmented reality and AI, firefighters could know where people are and how to predict fire's behavior.
- *Smart Grid:* The energy sector is regarded as uniquely critical because it provides an enabling function across all infrastructure sectors. The modern smart grid has two interwoven components: communication network and power grid. The duality of the smart grid creates a challenge to protect and defend the grid from attacks. The digital twin can be adapted to provide security for the smart grid.
- *Construction:* The construction industry is a sector that hosts a wide range of potential applications for digital twin. The DT technology can be applied in the development of smart city buildings or structures. The use of the DT and data analytics can provide greater accuracy when predicting and maintaining buildings. The DT also gives construction teams greater accuracy when carrying out simulations before the physical building.
- *Sports:* In the field of sports, researchers have used a digital twin to make virtual connections and monitor athletes in the lab. A team of human DTs can aim at mirroring the athletes' conditions (physical twins) and behaviors, with the aim of predicting their condition during training.
- *People/Workers:* Digital twin can represent people/workers including their data (weight, health data, activity data, and emotional status), which can aid in establishing models to better understand the wellbeing. In other words, human beings will also have their digital twins, which will collect real-time information from wearables. Digital twins of humans would also enable the collection and analysis of data to improve quality of life and enhance well-being. For example, in healthcare, a digital twin can be used to provide the virtual replica of a person, who employs a life-long data record to predict the state of health and provide answers to clinical questions.
- *Logistics:* Digital twins in logistics are creating new opportunities for companies to reexamine their properties: warehouse and distribution centers. The end goal of the digital twin in logistics is to achieve an unprecedented level of insight and visibility of the past, current, and future state of a subject. Digital twins can be used to automate packaging selection. Creating digital twins of shipping containers can also give shipping companies new visibility into their asset operations [11].

Figure 4 shows some of these applications [1].The progress made by the DT technology in these various application areas has led to the continuous development of their respective industries. Other applications of DT include built environment, digital design, digital production line, equipment status monitoring, product service, product maintenance, fault maintenance, product customization service, factory, vertical farming, production networks, renewable energy industry, oil and gas (O&G) industry, meteorology, monitoring, aircraft engines, locomotives, power plants, smart factories, smart buildings, and smart homes.

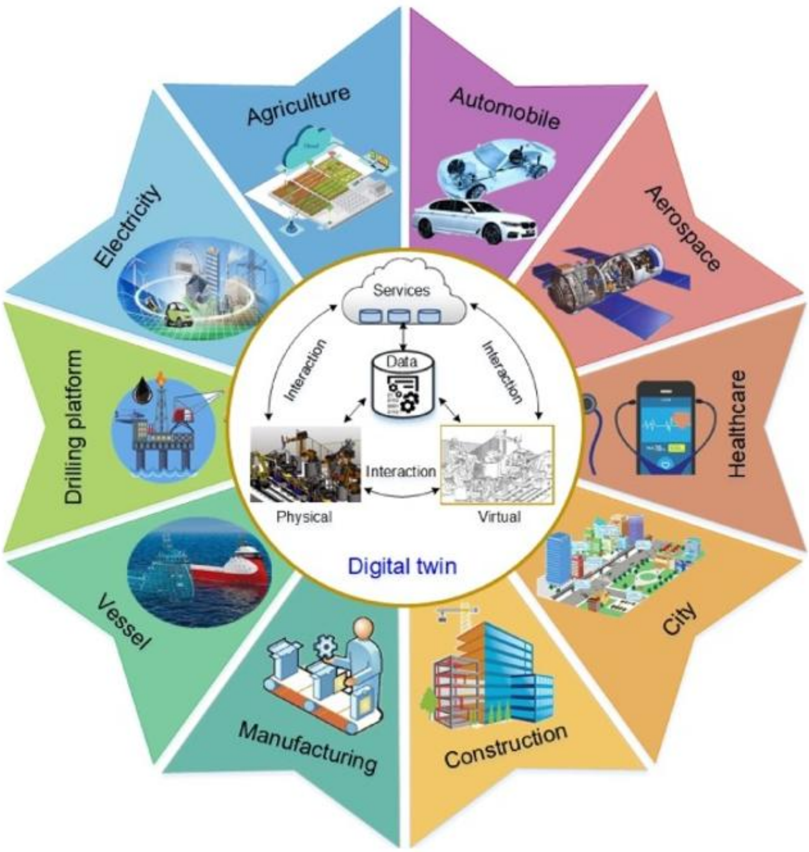

Figure 4: Different application fields of digital twin [1]

Benefits

DT has a lot of benefits. DT technology is becoming increasingly important for digitizing industry. It is listed as one of the six game-changing technologies for the defense industry. DT is helping to reduce cost and time, which would otherwise be wasted on the production. It is used for representing purposes as well as predicting the product behavior. Some manufacturers use DT to improve product design, while others use DT to improve product quality in manufacturing. DT enables designers to digitalize, visualize, and materialize the intangible concepts of complex system. Industrial services will be accurately predicting the future of physical assets through their digital twins.

Other benefits include [12]:

- Predict the future before building: DT will let you see how your device is going to perform before you actually build it.
- Easier troubleshooting: DT makes troubleshooting easier because it allows you to safely work through a problem in your test environment.
- Increase accuracy: Combining AI and machine learning could help speed up testing, as well as help you find issues you didn't know were lurking around the corner.
- Provide customer experience and usage data: DT is a great tool for development, deployment, and product updates.
- Reduce costs: DT reduces the operating cost.
- Efficient production control: It is an effective way of improving a business' productivity, reduce complexity, and increase efficiency. Many companies use digital twin to spot problems and increase efficiency.
- Optimization of operability, manufacturability, and sustainability: Its ability to link enormous amounts of data to fast simulation makes it possible to perform real-time optimization of products and

production processes. Digital twins have the potential to reveal insights from the past, optimize the present, and predict future performance.

Challenges

Although there is growing interest in digital twin technologies, there are still many reservations regarding its feasibility, and application. There are many challenges in constructing a digital twin. Another challenge lies in lack of clear standards for implementing digital twins, a need to train people to use them, and a plan for governance. Other challenges include [13]:

- *Trust*: This is a challenge both from the company point of view and that of the user. Model validation is one way to overcome the challenge with trust. Ensuring that digital twins are performing as expected is key for ensuring user trust.
- *Privacy and Security*: Privacy and security associated with digital twins are a challenge because of the vast amount of data involved and the risk this poses to sensitive system data. Security and privacy concern for digital twins data contribute to tackling trust issues with digital twins.
- *Standardized Modelling:* It is imperative to standardize technologies to interoperate in the long term. As of now, there is no standardized approach to modelling. A standard approach is necessary from initial design to a simulation of a digital twin. Standardized approaches ensure domain and user understanding while ensuring information flow between each stage of the development of a DT.

Future of Digital Twins

Digital twin is a revolutionizing concept and a cutting-edge technology. It is emerging as one of the key IT tools in many industries, especially in manufacturing. In the future, almost every manufactured product could have its own digital twin. Everything in the physical world would be replicated in the digital space through digital twin technology. There will be a proliferation of digital twins in the near future according to industry analysts. The global market for digital twins is expected to grow very rapidly. Digital twins hold the potential to change healthcare immensely in the future. They will allow the power to push past the limitations of medicine, and utilize data as a tool to truly understand the human body.

Interest in DT has greatly increased over the years across both academia and industry.

A lot of big names such as Microsoft, IBM, Bosch, and GE have started investing in this technology. Companies that lag behind may suffer a downfall. The Digital twin Interoperability Task Group is actively working on practical guidance on the use and application of digital twins.

Conclusion

Digital Twin is the imitation of the real world product, process or system. It may also be regarded as a digital replica of a living or non-living physical entity (asset, process or system). Although the digital twin is still in its infancy, it is far from realizing their potential, its significance for industry has become very visible. Digital twins, if truly embraced by an organizations, will usher in a completely new era. More information about digital twins can be found in the book in [14].

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