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# Digital Twins in Manufacturing: A Review

**T.Vijaya Babu [1], Dr.Prabakar [2]**

[1] Student (M.Tech), [2]Professor
[1,2]Computer Science Engineering, Lingayas Institute of Management and Technology,
Nuzvid Rd, Viveka Nagar, Madalavarigudem, Andhra Pradesh-521212

**Abstract**

Traditional manufacturing processes often face challenges such as poor real-time monitoring and interaction during machining, difficulties in diagnosing equipment failures, and significant errors in machining. Digital twin technology develops virtual models of objects digitally, simulating their real-world behavior based on data. Digital Twin (DT) is the advanced tool of smart manufacturing which provides a proper way to model, analyze, and control the physical systems. By developing an ever-evolving replica of the physical structures, systems or even operation lines, Digital Twins enable the functionality of exploring various demanding circumstances and schemata, all in order to make effective decisions. When the manufacturing environments are rapidly changing, and there are more interconnections between them, the use of Digital Twins is especially useful. It gives general information about its uses, such as in the processes, time-saving and safety measures. As well, the paper considers the difficulties related to the practical application of DT, including costs, data management, and requirements for the formation of standards.

**Keywords:** Digital Twin; Smart Manufacturing; Real-Time Data; Predictive Maintenance; Process Optimization; Manufacturing Efficiency

## 1. Introduction

A digital twin (DT)is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning, and reasoning to help decision making [IBM]. It can also be defined as a synchronized instance of a digital model or template representing an entity throughout its lifecycle and is sufficient to meet the requirements of a particular use case that the digital twin is meant to address. According to FANUC, the largest maker of industrial robots, "A digital twin is the concept of creating a digital replica of the physical machines, production processes or shop floor layouts in order to generate a number of competitive advantages." Moreover, "a digital twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" .

The digital twin can predict virtually everything that will happen in the physical world, thus providing valuable insights for future forecasting and development. This also allows testing and a better understanding of the product in the early stage, thus minimizing downtime and reducing cost. Digital twin technology is the future of designing and manufacturing a product, process, or service. The digital twin is being used in the development of robots and autonomous vehicles and their sensor suites to enable testing in traffic and environment simulations as shown in Fig:1 .

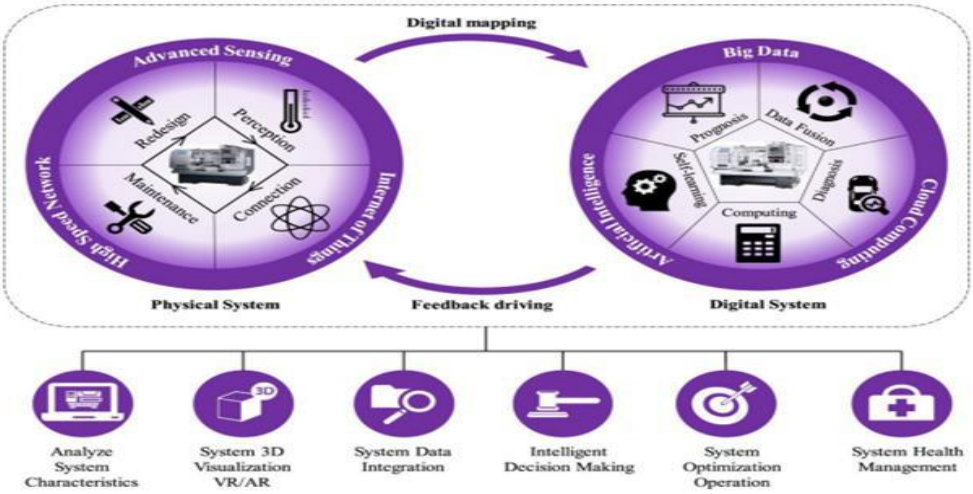


Fig1: The design of the digital twin for manufacturing

The digital twin implementation has a huge part to play in the testing, development, and validation of autonomous vehicles. The digital twin is also helping the healthcare industry through data by analyzing different circumstances of individual patients for their performance and by comparing them to the population and finding patterns to see trends. The digital twin also helps regulate and monitor the energy generation and capacity, especially wind turbines that can utilize the digital twin to integrate energy data and analyze energy growth avenues.

## 2. Digital twin in Smart Product Design

The digital twin greatly influences development, production, and operation by evolving through data flow, feedback via user experience, and incoming new data. A product's behavior can be simulated and analyzed well before its physical replica has been manufactured during product development. Three dimensional printing for product design also relies almost entirely on digital twins. In a recent study performed by Siemens for the mixing of gases in micro-mixers, insights from the simulation of form and flow behavior were combined with generative algorithms. This helped Siemens to develop a unique micro-channel shape and configuration, which increased the mixing efficiency significantly.

Digital twins can even help to simulate entire factories, including individual machines and their processes. As an example, let's consider the case of milling robots which experience large forces during the milling operation, leading to inaccurate movements. This problem can be solved by estimating these forces that push the robot away and compensating them in real time, keeping the robot in its path. With regards to operations, sudden disruptions caused due to sensor data of any real point in real-time can be compared to the simulation of that point and reliably predict the point parallel to operations using a digital twin. Digital twin opens new ways for development, production, and operations

## 3. Digital Twin in the Battery Industry

Digital twins show an optimal virtual model of a product or production plant, intuitively show development throughout the entire lifecycle, and easily show operators to predict behavior, optimize performance, and gain insights from previous design and production experiences. Siemens's comprehensive digital twin concept consists of three components a digital twin of products, a digital twin of production, and a digital twin of performance of products/production. Siemens is the only company that can make an offer from a holistic point of view, as it provides sufficient industry-specific expertise and optimized tools.

## 4. Digital Twin For Smart Bio-manufacturing

Developing a drug may cost a billion dollars and an average of ten years. Cell cultures in Petri dishes do not resemble organs or human diseases, and animal experiments are often unsuitable because animals are not human beings. Therefore, drug development is costly and takes much time. That is also true for toxicity tests for cosmetics, chemicals, and food products. Organ-on-a-chip (OOAC) technology has recently been introduced into the healthcare and personalized medicine industry to revolutionize bio-pharma research, development, and manufacturing OOAC technology has the potential to use artificial intelligence and machine learning to reduce drug discovery times and costs and the potential to replace animal testing by incorporating bioreactors, and tissue culture technologies. OOAC is a physical model of an organ or organs replicated on a device called a "chip." The chip involves growing tiny versions of organs from living cells in cavities and channels. In these devices, we can make three-dimensional cell cultures of human cells in an environment that closely mimics what is actually present in the human body.

## 5. Digital Twins And The Internet Of Things For SM

Digital twin for IoT is the way of virtually representing the elements and the dynamics of IoT operation and its working throughout its lifecycle. The ways in which the design, build, and operations of an IoT device are constructed are heavily influenced by the digital twin. In the design phase, different aspects of engineering work together synergistically to collaborate into a single facility of operational oriented design. Particularly, the physical components, along with the physical bill of materials (BOM), collaborate with the virtual components such as software, sensors, chips, etc. This collaboration brings out the highest quality product by virtue of the digital twin. In the build phase, the digital twin helps in better understanding the influence of the product's tolerances on the devices that make the product. Moreover, its also about the improvement of the manufacturing process through the correction of tolerances and outcomes that are desired in the product.

## 6. Digital Twin Solution In Machining Operation By FANUC

FANUC, a world leader in robotics and automation solutions, has developed technology for implementing digital twin technology in machining operations. This has been achieved using the newly released FANUC software, SURFACE ESTIMATION, on Victor Taichung's 5-axis machining center Vcenter-AX630. The objective of the application was to foresee the actual cutting texture on part surface by digital twin. The operation was affected by several factors such as (a) the mismatch between the tool paths generated by CAM and the actual cutting path; (b) unsatisfactory parameter settings of CNC control; (c) inefficient servo system response; and (d) thermal displacement, to name a few. The new software from FANUC has features to improve the shortcomings of the existing system. The software includes the machine servo parameters into the system to match the actual cutting operation. This gives the user the option to run the program on the real part only if the simulated result is satisfactory.

## 7. Challenges to Implement Digital Twin in Manufacturing

### 7.1 Time and Cost

The manufacturing sector, where cost reduction and production time reduction have the most emphasis, suffers a lot in DT technology because of high initial investment and operating costs. It may take time and many resources to create semantically exact and highly accurate mirrors of complex manufacturing systems. The necessity to use high-performance computers to reproduce processes and phenomena accurately makes the costs higher. The cost of DT implementation & the time that may be required to implement the same may form a major challenge for some enterprises particularly the small enterprise that may not be in a position to fund such advanced technology.

### 7.2 Data Related Issues

Manufacturing processes generate vast amounts of data, which are critical for an operation of DT. However, factors such as data privacy, ownership and data transparency raises major concern . Manufacturers have to also understand data governance policies that are specific to industries and regions. There is a fear of sharing the DTs' necessary data due to the security concerns of the proprietary information and the security of the sensitive data. This unwillingness or lack of willingness to share or use data because of privacy consciousness or compliance with regulations can hinder the formation of integrated and efficient DT in manufacturing .

## 8. Lack of Standards and Regulations

The manufacturing industry, which often relies on standardised processes and regulations, faces complications due to the absence of a unified framework for DT. With a huge range of DT models and architectures in existence, the lack of standardisation can lead to compatibility issues, making it difficult for different systems and components to communicate and function together seamlessly. This fragmentation can hinder the efficient design and integration of DTs in manufacturing, slowing down the adoption process. Moreover, without industry-wide standards, ensuring the security and accessibility of data across different platforms becomes a challenge, potentially leading to operational inefficiencies and increased risks .

## 9. Future Trends of Digital Twin in Manufacturing

The COVID-19 pandemic in 2020 is one among the causes propelling the need for DT across several industries. This viral pandemic has led to an upsurge in demand for DT in the industrial, healthcare, and pharmaceutical sectors. The industrial and aerospace industries have made use of DT technology, but DT is still in its infancy in a number of other industries, including a construction, healthcare, automotive, and agricultural sectors. General Electric is of the opinion that the automobile industry as a whole, from manufacturers to individual consumers, will embrace DT technology as predictive maintenance and analytics continue to progress. Auto owners will no longer have to worry about unexpected breakdowns and the car may even arrange maintenance appointments autonomously, making auto maintenance a breeze. Prior to the appointment, the technicians and the service department will have access to all the vehicle's information, which will enable them to provide faster and more effective solutions.

DT's growth in the agricultural business is still in its early phases. DT can be used to store and collect data, it can organise actions in complex workflows, it can automate data analysis, it can learn and measure the soil's content and capacity, it can simulate crop outcomes, it can predict the weather, and it recognises when resources are being strained by things like pollution, invading species, low soil quality, and so on .

## 10. **Conclusion and Future Work**

By creating a virtual replica of physical systems, DT facilitates real-time monitoring, simulation, and analysis, leading to improved decision-making and efficiency. Despite the advantages, challenges such as high costs, lack of standardisation, and data-related issues hinder widespread adoption. The potential of Digital Twins extends beyond manufacturing to sectors such as automotive, healthcare, and agriculture, where their application could revolutionise practices and outcomes. An integration of DT technology into smart manufacturing represents a significant advancement in optimising production processes, enhancing product quality, and reducing costs.

Addressing the present difficulties of deploying DT technology, including creating cost-effective solutions and creating industry-wide standards, should be the focus of future research. Exploration of advanced techniques like AI-driven analytics and integration with emerging technologies such as mixed reality could further enhance the capabilities of Digital Twins. Additionally, expanding applications to new sectors and improving interoperability between different systems will be crucial for maximising the benefits of DT.

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