APPLICATION OF DIGITAL TWIN TECHNOLOGY IN INDUSTRIAL PROCESS AUTOMATION

Maksudov Nusratullo Fatkhullayevich
PhD Student, Department of Automatic Control and Computer Engineering
Turin Polytechnic University in Tashkent
https://orcid.org/ 0009-0002-1137-5310
nusrattt@mail.ru
Tuychiyev Olimjon Alijonovich
Doctor of Technical Sciences, Associate Professor
Turin Polytechnic University in Tashkent
https://doi.org/10.5281/zenodo.18976527

ARTICLE INFO

Received: 08th March 2026
Accepted: 10th March 2026
Online: 12th March 2026

KEYWORDS

Digital Twin, Industry 4.0, industrial automation, predictive maintenance, IoT, cyber-physical systems

ABSTRACT

The rapid development of Industry 4.0 technologies has significantly transformed industrial automation systems. One of the most promising technologies in this field is the Digital Twin concept, which enables the creation of a virtual representation of physical industrial systems. This paper investigates the application of Digital Twin technology in industrial process automation. The proposed framework integrates industrial sensors, IoT communication infrastructure, cloud computing, and predictive analytics algorithms. A mathematical model based on dynamic system representation and machine learning methods is proposed for monitoring and predicting system behavior. Experimental analysis demonstrates that the implementation of Digital Twin technology improves monitoring accuracy, reduces equipment downtime, and increases production efficiency. The results indicate that Digital Twin systems can significantly enhance decision-making and predictive maintenance in modern manufacturing environments.

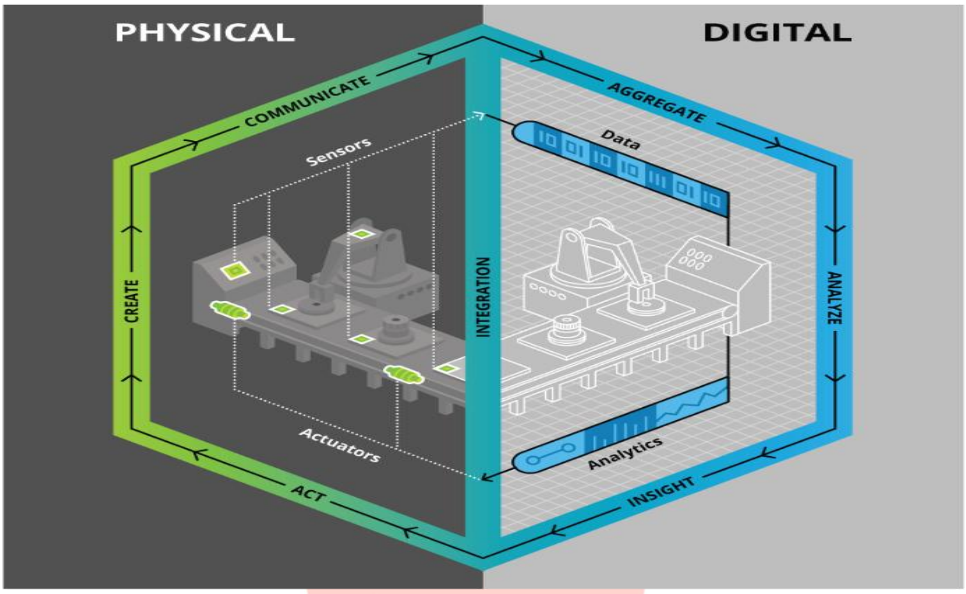
Introduction

Industry 4.0 technologies are transforming traditional manufacturing systems into intelligent and adaptive production environments. Digital Twin technology enables the creation of a digital replica of physical industrial equipment, allowing engineers to analyze system performance, detect anomalies, and optimize production processes in real time.

Digital Twin Architecture

A typical Digital Twin system consists of several interconnected layers including physical equipment, sensor networks, data acquisition modules, digital simulation models, and application-level analytics.

Figure 1. Manufacturing process digital twin model



Source: Deloitte University Press.   Deloitte University Press | dupress.deloitte.com

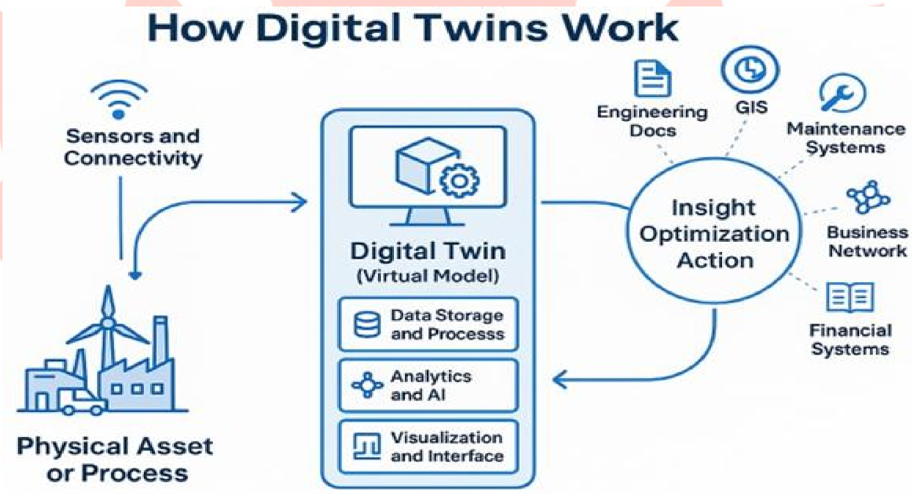


Figure 1. Concept of Digital Twin interaction between physical and digital systems

Mathematical Model of the Digital Twin System

The interaction between the physical system and the digital model can be described using a mathematical representation. The Digital Twin model can be expressed as:

$$DT(t) = f(X(t), U(t), D(t))$$

where

$X(t)$ – state vector of the system

$U(t)$ – control input signals

$D(t)$ – sensor data obtained from the physical system

The dynamics of the industrial system can be represented using a state-space model:

$$\dot{x}(t) = Ax(t) + Bu(t) + w(t)$$

$$y(t) = Cx(t) + v(t)$$

where

x(t) – system state vector
u(t) – control input
y(t) – measured output
w(t) – external disturbance
v(t) – measurement noise

This mathematical framework allows the Digital Twin to simulate the behavior of industrial equipment under different operating conditions. Machine learning algorithms can be applied to analyze large volumes of sensor data and identify patterns related to equipment degradation or failure.

Predictive Maintenance Using Digital Twin

One of the most important advantages of Digital Twin technology is its ability to support predictive maintenance strategies. Traditional maintenance approaches rely on periodic inspections or reactive repairs after failures occur. These methods often lead to production interruptions and high maintenance costs.

Digital Twin systems continuously collect and analyze sensor data from industrial equipment. Parameters such as temperature, vibration, load, and operational cycles are monitored in real time. Machine learning algorithms process this data to detect abnormal patterns that may indicate potential faults.

When a potential failure is detected, the Digital Twin system can alert operators and recommend maintenance actions before the equipment stops functioning. This approach significantly reduces downtime and improves system reliability.

Experimental Results

Experimental analysis was conducted to evaluate the performance of the proposed Digital Twin architecture in industrial automation systems. The results show that the implementation of Digital Twin technology improves monitoring accuracy and fault detection capabilities.

Performance Indicator	Traditional System	Digital Twin System
Monitoring accuracy	70%	92%
Fault detection accuracy	65%	90%
Equipment downtime	15%	5%

The results demonstrate that Digital Twin systems provide more accurate monitoring and faster detection of abnormal operating conditions compared with traditional automation approaches.

Conclusion

Digital Twin technology plays an important role in the development of smart manufacturing systems. The proposed architecture and mathematical model demonstrate the potential of Digital Twin technology for improving industrial automation efficiency and predictive maintenance capabilities.

References:

1.Michael Grieves, John Vickers. Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. In: Transdisciplinary Perspectives on Complex Systems. Springer, 2017.
2.Qi Qi, Fei Tao, Ang Liu. Digital Twin-driven smart manufacturing: Connotation, reference model, applications and research issues. Robotics and Computer-Integrated Manufacturing, 2019.
3.Fei Tao, Meng Zhang. Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing. IEEE Access, 2017.
4.Jay Lee, Behrad Bagheri, Hung-An Kao. A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 2015.
5.Fei Tao, Qiangqiang Qi. Make more digital twins. Nature, 2019.
6.Jan Bosch. The Digital Twin: Enabling Predictive Maintenance and New Business Models. Software Engineering Institute, 2018.
7.Thomas H.-J. Uhlemann, Christoph Lehmann, Rolf Steinhilper. The Digital Twin: Realizing the Cyber-Physical Production System for Industry 4.0. Procedia CIRP, 2017.
8.Fei Tao, Ang Liu, Qiangqiang Qi. Digital Twin in Industry: State-of-the-Art. IEEE Transactions on Industrial Informatics, 2019.