International Journal of Advanced Culture Technology Vol.10 No.3 397-403 (2022)
DOI https://doi.org/10.17703/IJACT.2022.10.3.397

IJACT 22-9-47

Study on the Interoperability of Digital Twin Systems

[1]Joon-Ik Kong

[1]Telecommunication Technology Association
joonik2000@gmail.com

Abstract

The world is paying a lot of attention to digital twins to preoccupy future technological competitiveness. Digital twins can be used in various fields such as manufacturing, medical care, and cities. Various market research institutes predict that the market size of digital twins will gradually expand. Korea has also selected digital twin as one of the representative tasks of the Korean version of the New Deal and is promoting related policies. However, a common platform or standard for building digital twins is not enough. Interoperability is a very important characteristic for the purpose of creating new value through interconnection between digital twins rather than independently developing and utilizing digital twins. The Digital Twin Consortium is an international council for the effective development and utilization of digital twins, and is working to solve the problem of digital twin interoperability. The Digital Twin Consortium recently published the 'Digital Twin System Interoperability Framework', and this paper analyzes the digital twin interoperability based on it.

Keywords: *Digital Twin, Interoperability, Digital Twin Consortium (DTC), Digital Twin System Interoperability Framework*

1. INTRODUCTION

The world is now at the center of the digital transformation era. In the past, computers could understand analog information simply by converting analog information into digital information, but recently, it has been transformed into a digital technology-oriented business by proposing new business models through advanced software technologies such as Big Data and AI [1]. Cyber information gives you a range of benefits, including real-time decision-making, efficiency and productivity improvements, and agile response to customer needs. According to a global survey of senior executives conducted by McKinsey, digital technology is being actively utilized to overcome the pandemic crisis and meet requirements such as the digitalization of business processes and legacy systems, and related businesses are growing rapidly [2].

Digital twins are one of the key technologies in the era of digital transformation. Gartner, an authoritative market research company in the U.S., will announce "strategic technology trends" that will emerge as major technologies in the next three to five years. They selected digital twins for three consecutive years from 2017 to emphasize the importance of technology. In addition, Korea is actively responding by including "digital twin" in the top 10 representative tasks of the "Korean New Deal" in 2020.

Manuscript received: August 05, 2021 / revised: August 31, 2022 / accepted: September 06, 2022
Corresponding Author: joonik2000@gmail.com
Tel:*** - **** - ****
Telecommunication Technology Association
Principal Researcher, Software Testing & Certification Laboratory, Korea

Digital Twin is a technology that reproduces real objects and systems in a digital environment. It can be implemented by combining various technologies such as IoT, artificial intelligence, big data, AR/VR, and 3D modeling. Various use cases can be accurately predicted or simulated based on real-world environmental data collected in real-time. Table 1 shows the expected advantages of a digital twin.

Table 1. Benefits of the digital twin

Visibility	The status of physical resources is updated in real-time and displayed on the screen as a three-dimensional model, allowing users to intuitively monitor and make decisions.
Increase productivity	Product design can be optimized by reflecting the needs of various users, and the product can be experienced in advance through simulation before product completion, eliminating potential failures and reducing time to market.
Reduce energy consumption	Real-time visibility into the energy consumption of physical resources allows you to quickly replace or removed performance-degrading factors.
Reduced maintenance costs	Through the continuously collected status information of physical resources, it is possible to predict and respond to maintenance timing.

Digital twins are being used in various fields such as manufacturing, medical care, and city. According to Markets and Markets, a market research firm, the global digital twin market is expected to reach $3.1 billion in 2020 and $48.2 billion in 2026, and the use of digital twins in various fields is expected to increase [3]. In recent years, companies providing digital twin solutions (General Electric's Predix, Siemens' MindSphere, Microsoft's Azure Digital Twin, Ansys' Twin Builder, etc.) have been collaborating to build more efficient digital twins [4].

Although the diffusion of digital twins is progressing rapidly, there is a lack of a common platform or standard for building digital twins. Users are independently developing digital twins based on their own needs, and the silo phenomenon is occurring. In the future, a single optimized digital twin must be interconnected and autonomously optimized [5, 6]. In this process, interoperability issues for data exchange and interworking between different digital twins must be considered. Interoperability-related issues include identifying and responding to complex causal problems, simulating and preserving integrated environments on multiple domains, and collaborating among stakeholders across industrial ecosystems [7-9].

The definition of digital twin interoperability has not yet been defined by an international standard. The international standard for IoT interoperability, the core technology of digital twins, is defined in ISO/IEC 21823-1 as 'the ability to be transmitted and programmed by users without prior knowledge of data transmission [10].

This paper was analyzed based on the 'Digital Twin Systems Interoperability Framework' recently published by Digital Twin Consortium [11].

2. DIGITAL TWIN CONSORTIUM(DTC)

Digital twins are built at a variety of scales depending on the needs of the users. From simple digital twins simulating robotic arms making coffee in robotic cafes to large digital twins like Singapore's smart city [12].

However, problems arise as digital twins grow in size. As systems grow in scale, digital twins have more physical objects to simulate, and each physical object is typically created by multiple manufacturers rather than one. It also requires a network protocol for exchanging information between physical entities. Therefore, digital twins must solve complex problems to seamlessly simulate disparate physical objects and fuse disparate technologies.

The DTC was launched in May 2020 under the auspices of the Object Management Group (OMG) as an international council for effective digital twin development and use. Founding members include Ansys, Dell Technologies, Lendlease, and Microsoft [13].

The purpose of DTC is to unite industry, government, and academia to ensure consistency in vocabulary, architecture, security, and interoperability of digital twin technologies. Due to the lack of prescribed standards or terms for digital twins, companies are complaining of difficulties in introducing digital twins. DTC is working to enable digital twins in many companies through standards development, open standards proposals, and sharing of best practices.

The objectives of the DTC are as follows.

• Improved interoperability of digital twin technologies
  - Ensure digital twin models interoperate across product lifecycles
  - Develop best practices for security, privacy, and reliability
  - Create a library for reference implementations of digital twins

• Accelerate the Digital Twin Market
  - Establish de facto industry guidelines for digital twin technology
  - Development of industry requirements for new digital twin standards
  - Reduce skill gaps through employee engagement

• Demonstrate value to maximize results
  - Integrate existing source code
  - Affects market direction and helps projects deploy and operate quickly
  - Combining resources and reducing risk

3. DIGITAL TWIN SYSTEM INTEROPERABILITY FRAMEWORK

Table 2. Seven key concepts of a system interoperability framework

System-Centric Design	It creates a System of Systems (SOS) within a domain or across multiple domains to enable collaboration in mechanical, electronic, and software disciplines.
Model-Based Approach	Given the millions of interconnections, designers need to be able to code, standardize, identify, and reuse models in a variety of use cases in the field.
Holistic Information Flow	Facilitates understanding of the real world for optimal decision-making. A "world" here can be a building, utility, city, country, or other dynamic environments.
State-Based Interactions	The system state includes the values of all static and dynamic properties at a point in time.
Federated Repositories	For optimal decision-making, heterogeneous information distributed across multiple dimensions of digital twins must be accessible and correlated.
Actionable Information	Information exchanged between subsystems constituting SoS enables effective action.
Scalable Mechanisms	Interoperability mechanisms should be able to scale from the interoperability of the two simplest systems to the interoperability of dynamic federations of distributed, autonomous, and heterogeneous systems within a complex global ecosystem.

DTC announced the Digital Twin Systems Interoperability Framework on December 7, 2021. The main goal of the framework is to provide an initial ecosystem that will enable seamless interoperability for large-scale systems and influence the proliferation and integration of digital twins through a process of continuous review and improvement of scalable interoperability mechanisms. For example, consider expanding the digital twin of a smart building into a smart city, a smart national digital twin, or connecting a factory to other factories.

The framework derives seven key concepts in terms of design for the interoperability of large-scale systems.

3.1 System-Centric Design

Products coming to market require a system-level approach to ensure fast interoperability. A system can be viewed as a group in which components interact according to a set of rules. Each component system can operate independently, but must be connected to each other to perform more functions. In other words, it must be a SoS that interacts within multiple domains, not just domains.

The framework classifies systems into digital systems, cyber-physical systems, and physical systems. Digital systems refer to organizations and companies of all sizes that implement and operate objects as computing elements for the management, processing, and storage. These are artificial intelligence, machine learning, analysis engines, applications, and services. Cyber-physical systems include analog-to-digital, digital-to-analog converters, embedded and the Internet of Things, and provide an interface between digital and physical systems. Physical systems include man-made systems, including humans. In general, subsystems are structurally contained, and these subsystems do not operate independently but support each other.

System-centric design requires the following simple approaches. First, any system is the building block of a digital twin. Second, each system must be interconnected to ensure interoperability. Third, it should be considered that the system connections can change continuously or dynamically. Finally, any system can be configured in a multi-step manner.

3.2 Model-Based Approach

Conceptual models help users understand the system by providing a visual representation of the structure and behavior of the system. The framework describes seven conceptual models.

- Goal-Oriented model: set goals to be achieved through digital twins, and achieves the goals through interaction between digital twins.

- Digital and physical model: represent physical (device, person), digital (API, data), or logical (organizational system, business unit, work center) structure based on the behavior and state of the system.

- Information models: modularize to the smallest units to ensure interoperability, and consider scalability and reuse.

- Simulation model: iterative improvement process is performed to explain and predict the results that will be reflected in the real world based on various information about the uncertain real-world.

- Messaging model: determine how messages are sent and received between systems and are independent of the communication protocol.

- Connection model: connect describes the realization of value through relationships between systems. It should be modeled according to the requirements and purpose of the connection, considering communication parameters, the messaging format, semantics, protocols, access, and security criteria.

- Model of the model (metamodel): describe the model and all systems share a standard metamodel to encapsulate internal behavior, function, purpose, etc., enabling interoperability.

3.3 Holistic Information Flow

The main purpose of digital twins is to help you understand the overall environment for optimal decision-making. You can reference multiple domains or use cases to get a holistic understanding. The flow of information considers one-way and two-way. Analytical applications require a one-way flow, but a two-way flow of information is required to analyze data measured by sensors and actuate actuators with command messages. In addition, the optimal decision-making and action of digital twins are made through artificial intelligence and machine learning, so iterative process improvement is required. The history of information shared by interconnected objects in digital twins is an important part of overall understanding and decision-making. This information has a unique life cycle, such as transmission, storage, and retrieval, and must ensure the fidelity and governance of information according to the life cycle. Fidelity represents the degree to which the model and simulation of the system can reproduce a function or operational state. Governance deals with policies or processes for data management.

3.4 State-Based Interactions

The state information of a system is very important information that is essentially used in the field of computing systems, and information about state changes can be synchronized with other systems through the information exchange process (event notification, messaging).

The state of the system represents the values of static and dynamic properties of each element at a specific point in time. And the state of the system changes according to any event inside or outside the system. State changes can be considered as inputs and outputs to stateful system processes expressed as system states or interdependencies with external systems.

3.5 Federated Repositories

Modern computing systems are increasingly distributed. Even small systems that are likely to operate independently form a federation of interconnected systems with many subsystems to achieve the purpose of the system. In particular, this information is not located in a specific location but exists in the form of distributed storage using various storage technologies such as edge and cloud. Large and complex digital twin systems can contain information from different domains and heterogeneous subsystems. To ensure interoperability, certain technologies and limitations must be considered, such as translators and gateways that can normalize domain information. In addition, security management is for information access and use.

3.6 Actionable Information

In a framework, information is simply consumed or used in a response, or the system is leveraged to make intelligent judgments. Semantic interoperability enables contextual interpretation of the meaning of information. Information is ontology-based data considering metadata exchanged between different systems and environments. This is a high level of interoperability that transcends syntactic interoperability considering the format of the information exchanged. For syntactic interoperability, information is exchanged in a receiver-optimized format.

Digital twins must preserve the characteristics of systems that behave as expected, regardless of the type of information. These includes safety, security, privacy, reliability, and resilience. In addition, confidentiality and integrity should be ensured in the process of information exchange between systems that make up SoS while maintaining system autonomy and interoperability.

The information must be recorded for auditing and analytical purposes and must be accessible at any time. For complex digital twins, the information source is an important determinant of the effectiveness of information analysis.

The amount of time a digital twin measures an object depends on the measurement interval, such as milliseconds, minutes, or days. At this point, the system needs to understand other systems that are using or utilizing this information to ensure the timeliness of the information in a predictable way.

The systems that make up the digital twin may have different quality requirements for information. Interoperability between systems must respect these differences and enable the exchange of information between systems on a high-fidelity basis. In addition, this information should be able to manage and monitor the flow.

3.7 Scalable Mechanisms

Implementing interoperable systems requires that interoperability mechanisms extend from the interoperability of two simple systems to the interoperability of complex distributed, autonomous and heterogeneous systems containing millions of systems. There Therefore, digital twins must provide a mechanism for securely sharing information, including metadata about system connections. First, it must be simple to design and implement to be extensible. To ensure interoperability of heterogeneous devices, adapters must be supported and communication protocols and data formats must match. To be a scalable add-on system, it must be dynamically reachable. Interoperability mechanisms should automate the discovery, feature matching, and interoperability of other systems. System discovery requires a filtering system that allows discovery based on predefined information and use cases and requires compatibility between numerous candidate systems. Systems connected through mechanisms must match the roles and functions of the information flow. Finally, it must be interoperable while maintaining reliability and performance.

4. CONCLUSION

Digital twins are gaining worldwide attention, but there is still a lack of a common platform or standard for digital twins. Since being selected as a strategic technology by Gartner in 2017, companies around the world have been working to secure digital twin technology, but now they are developing their own digital twins or providing their own solutions as needed. This can cause serious interoperability issues as digital twins scale in the future.

Developing interoperability standards for digital twins is not easy. There are many challenges to overcome, including integration challenges with existing systems, heterogeneous devices, and various data formats. DTC's framework approaches the question of interoperability by modeling any system represented as a digital twin from an abstract point of view so that it can be applied to all cases. So while it is possible to understand the overall behavior of digital twins, it is necessary to get concrete examples of their application in real-world systems. For example, how to solve compatibility issues between old and new protocols to provide real-time communication in a distributed environment.

We analyzed seven concepts described in DTC's 'Digital Twin Systems Interoperability Framework'. Based on this result, the interoperability problem of distributed heterogeneous systems can be solved. Through a continuous review and improvement process, the digital twin interoperability standard should be developed and specific use cases that can be used in the real environment should be accumulated.

REFERENCES

[1] Jason Bloomberg, “Digitization, Digitalization, And Digital Transformation: Confuse Them At Your Peril,” Forbes article, 2018

[2] Evan Williams, Jeff Galvin, Laura LaBerge, “The new digital edge: Rethinking strategy for the postpandemic era,” McKinsey Digital article, 2021

[3] Digital Twin Market by Technology, Type (Product, Process, and System), Application (predictive maintenance), Industry (Aerospace & Defense, Automotive & Transportation, Healthcare), and Geography - Global Forecast to 2026

[4] Maulshree Singh, Rupal Srivastava, Evert Fuenmayor, Vladimir Kuts, Yuansong Qiao, Niall Murray and Declan Devine, “Applications of Digital Twin across Industries: A Review,” Applied Sciences, 12(11), 5727, 2022

[5] Gartner, “Use the IoT Platform Reference Model to Plan Your IoT Business Solutions,” 2016

[6] Y. Kim, S, Yoo, H. Lee, S. Han, “CHARACTERIZATION OF DIGITAL TWIN,” Electronics and Telecommunications Research Institute, 2021, DOI: 10.22648/ETRI.2020.B.000017

[7] H. Lee, “Design of Ontology-based Information Model for Software Interoperability in Smart Factory,” International Conference on Convergence Technology (ICCT), 2016

[8] Anderson Luis Szejka, Osiris Canciglieri Junior, “The Application of Reference Ontologies for Semantic Interoperability in an Integrated Product Development Process in Smart Factories,” Procedia Manufacturing, vol. 11, 2017, DOI: https://doi.org/10.1016/j.promfg.2017.07.267

[9] H. Lee, S. Yoo, Y. Kim, “Status of Smart Factory Technologies and Standardization,” Electronics and Telecommunications Trends, 2017

[10] ISO/IEC Organization, ISO/IEC 21823-1 Internet of things (IoT) - Interoperability for iot systems - Part 1: Framework, 2019

[11] Anto Budiardjo, Doug Migliori, “Digital Twin System Interoperability Framework,” Digital Twin Consortium whitepaper, 2021

[12] Ehab Shahat, Chang T. Hyun, Chunho Yeom, “City Digital Twin Potentials: A Review and Research Agenda,” Sustainability, 13(6), 2021

[13] https://www.digitaltwinconsortium.org/