Federated Digital Twin Implementation Methodology to Build a Large-Scale Digital Twin System

2024 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB) | 979-8-3503-6426-2/24/$31.00 ©2024 IEEE | DOI: 10.1109/BMSB62888.2024.10608284

Myung-Sun Baek[1, 2], *Member IEEE*, Euisuk Jung[1], Young Soo Park[1], Yong-Tae Lee[1, 2]

1: Eletronics and Telecommunications Research Institute (ETRI)
Daejeon, Korea
2: University of Science and Technology (UST)
Daejeon, Korea
{sabman, esjung, yspark, ytlee}@etri.re.kr

***Abstract*—This paper considers an implementation methodology for large-scale digital twin system. In our research, federated digital twin implementation methodology is proposed to build the large-scale digital twin system. In the proposed methodology, multiple single digital twin system can be connected and the output data of the multiple digital twin systems is federated. Typically, a single digital twin system is developed to digitally mimic a single physical object, system, or single process. Therefore, in the proposed methodology, the large-scale digital twin can be implemented based on federation of multiple single digital twin systems. To federate the multiple single digital twin systems, single digital twin management, validation and federation techniques are required. Therefore, proposed methodology suggests the architecture and functions of the digital twin federation system.**

Keywords*—*Digital twin, federation, federated digital twin

I. INTRODUCTION

The digital twin is an interesting and famous subject in an industrial area, and various industry fields have considered the adoption of digital twin technology [1]. The digital twin duplicates physical objects (people, objects, spaces, systems, processes, etc.) in the real world into digital objects in the digital world, and provides various simulations for solving problems in the real world, or for correction and improvement [2]. The general purposes of the digital twin are:

- To minimize the cost of solving problems in the real world: The real world is simulated as a virtual world
- To prevent real world problems in advance: Past and present information collected from the real world is analyzed in the virtual world and risk factors are identified.

However, when building a digital twin of a large-scale real world, such as an entire airplane jet engine production facility or a smart new city, a very large number of objects and large, complex real-world structures need to be digitized. Therefore, the complexity of building a digital twin of a complex facility or large-scale real-world structure is exponentially higher than the complexity of building a digital twin of a small single system. In this paper, we consider federated digital twin methods. The methodology of federated digital twin implementation is to build one large digital twin system by linking many small single digital twins. The basic concept is to connect the required single digital twins based on the user's purpose among many small single digital twins, and to build a large-scale federated digital twin system that can meet the user's requirements. If a large-scale digital twin is constructed by federating single digital twins as described above, it is possible to utilize existing single digital twins, and each single twin can be operated individually. Furthermore, to manage and federate the multiple single digital twin system, the architecture and required functions of the digital twin federation system are suggested.

II. ARCHITECTURE FOR FEDERATED DIGITAL TWIN SYSTEM

In the federated digital twin, multiple digital twins work together. Therefore, the federated digital twin system should consider multiple single digital twin systems. Fig. 1 describes the federated digital twin system architecture. A single digital twin system wants to register with the federation layer. The federation layer assigns metadata to the newly registered single digital twin system. The metadata is generated based on the federation layer's metadata creation and management scheme. Therefore, the federation layer uses metadata from each single digital twin system to identify a single digital twin system.

The user requests the application service of federated digital twin system though graphic user interface (GUI). Digital twin selection module selects the required single digital twin systems to meet the user request. The digital twin selection module sends the list of the required single digital twin systems to the federation layer. The federated digital management module requests the required data of the selected multiple single digital twin systems, and the selected digital twin systems send the required data through the federated digital twin interface. After receiving the required data from multiple digital twin system, the federated digital twin management module sends the received data to the digital twin and data validation module. The data validation module checks the data quality and detects the anomaly data from the received data. After validation, the federated digital twin management module sends the validated data to the synchronization module. The synchronization module synchronizes data from multiple digital twin systems,

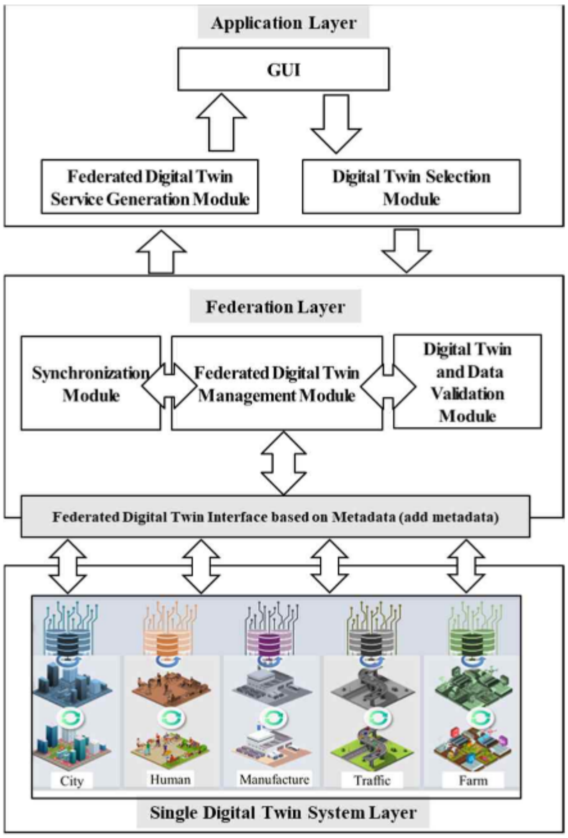

Fig. 1. Architecture of federated digital twin system

temporally and spatially. The synchronized federated data from multiple digital twin systems are sent to the federated digital twin service generation module in the application layer. The federated digital twin service generation module creates the service based on the federated data from the multiple digital twins according to the user request. Eventually the user can use the federated digital twin service. By operating the federated digital twin constructed in this way, various services based on large-scale system can be performed.

III. Operation and Expression of Federated Digital Twin System

The digital twin system is considered as a function including input and output. In the river digital twin system, we can consider the input objects (or variables) and output objects as follows:

- Input objects: rainfall, snowfall, flow rate, water volume, etc.
- Output objects: whether the river is flooding, when water recreation is good, etc.

Furthermore, we can consider the manufacturing digital twin as follows:

- Input objects: raw parts, manufacturing equipment, manufacturing processes, etc.
- Output: the time it takes to produce one manufactured product, the amount of production over a period of time, etc.

Therefore, the single digital twin system can be written as

$$T_1 = f_1(\boldsymbol{X}_1) \tag{1}$$

where, f_1 is function of single digital twin process, and T_1 is output value of single digital twin function. X_1 is input variable of single digital twin which can consist of multiple variables as follows:

$$\boldsymbol{X}_1 = [x_1(1), x_1(2), \cdots, x_1(L)] \tag{2}$$

where L is the number of input variables.

Federated digital twin model can be written as follows:

$$T_F = F(f_1(\boldsymbol{X}_1), f_2(\boldsymbol{X}_2), f_3(\boldsymbol{X}_3), \cdots, f_k(\boldsymbol{X}_k), \cdots, f_K(\boldsymbol{X}_K))$$

where $F(\cdot)$ is function of federated digital twin, T_F is output value of federated digital twin. And $f_k(\boldsymbol{X}_k)$ is k-th single digital twin function whose output value is T_k. The federated digital twin can also be modeled as the federated output of multiple single digital twin systems, as shown in the following equation,

$$T_F = F(T_1, T_2, T_3, \cdots, T_k, \cdots, T_K)$$

where T_k is output of k-th single digital twin system. According to this federation method, the large scale digital twin system can be implemented and operated.

IV. Conclusions

This paper proposes the large-scale digital twin implementation method based on federated digital twin. To develop and manage the federated digital twin system, federated digital twin system architecture is suggested. The federated digital twin system is developed by federation of multiple single digital twin systems. Therefore, to efficient expression of the federated digital twin system operation, mathematical modeling is introduced. Based on the federated digital twin implementation methodology and operation modeling, the large-scale digital twin system can be easily implemented and operated.

Acknowledgment

This paper was supported 100% by IITP grant funded by ICT R&D program of MSIT in 2024 year (No. 2022-0-00545, Development of Intelligent digital twin object federation and data processing technology)

References

[1] M. Grieves and J. Vickers, “Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems,” Transdisciplinary Perspectives on Complex Systems. Cham, Switzerland: Springer, pp. 85–113, 2017.

[2] M. -S. Baek, "Digital Twin Federation and Data Validation Method," 2022 27th Asia Pacific Conference on Communications (APCC), Jeju Island, Korea, Republic of, 2022, pp. 445-446, Oct. 2022.