Dynamic Analysis of Digital Twin System Based on Five-Dimensional Model

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Abstract. The practical application level of digital twinning technology has always been far from people's expectations. In order to make the digital twinning technology develop better, it is urgent to explore the internal causes of this kind of drop. Based on the theory of digital twinning five-dimensional model, combined with the actual situation of software development, dynamically analyze the working state of digital twin system, observe and discover the working conditions of various structural elements in the work of digital twin system, and propose the data of twins in digital twin system. The existence method, clear the concept of multiple virtual entities in the digital twin system, propose the principle that the service elements must be combined with the physical/virtual entities, summarize the organizational structure and operation rules of the digital twin system, and summarize the principles of a series of digital twin systems. The concept points out how to reduce manual operations to improve the operation of digital twin systems. The conclusions based on the five-dimensional model of the digital twin system are universal and can provide reference for the establishment and management of various types of digital twin systems.

1. The purpose and function of digital twin and the system concept of digital twin

Historically, for some huge and complex things that are difficult to complete experiments with physical objects, people have adopted the twin model of mapping with physical objects to simulate the operation of physical objects and complete alternative experiments or operations.

When the measurement technology and communication technology develop to a certain extent, the communication links between the physical object and the twin model are established, and the automatic information exchange occurs, which forms an automation system.

When the computer technology develops to a certain extent, people further put forward the idea of replacing physical model with virtual digital model. In 2003, Professor Grieves of the University of Michigan proposed the concept of mirrored spaced model. Then in 2011, he used the term "Digital Twin" in his book Almost Perfect: Driving Innovation and Lean Products through PLM, and it is still in use today. Because the limitation of physical modeling is broken, digital model can theoretically involve more details and simulate more functions. In modeling, it can break the limitation of site and ignore the cost of valuable materials. Compared with physical model, digital model has inherent advantages in receiving and outputting information.
The whole structure of digital twin is initially described as composed of physical entity, virtual entity and the connection between them. This definition is still in the idea of the concept of digital twin system, without further substantial decomposition and analysis.

Since the concept of digital twin has been put forward for about 10 years, virtual entity modeling, physical entity and the connection technology between virtual entities were difficult to meet the requirements of practical application, and the application of digital twin has been in a primitive and single-scene state.

In 2013, Germany proposed "Industry 4.0" and in 2015, China proposed "Made in China 2025" [2-10]. Both of the world's manufacturing powers have identically identified intelligent manufacturing as the core of a new scientific and technical revolution. The framework of intelligent manufacturing is the Cyber-Physical System (CPS), where Product Lifecycle Management (PLM) is implemented by digital means, and efficient product design, manufacture and supply are realized by digitalization and intellectualization. As the core technology in the field of intelligent manufacturing, digital twin becomes one of the keys to realize CPS. It is expected that digital twin can be applied to multi-scene in every stage of product lifecycle [12-21], which puts forward requirements on the information range simulated and mapped by digital twin system and the application and development of digital twin system. The original conceptual structure definition cannot satisfy the development of digital twin technology.

Tao Fei of Beihang University put forward the five-dimensional model of digital twin in 2018, and theoretically constructed and described the working process of digital twin model. In the five-dimensional model, there are five elements: physical entity (PE), virtual entity (VE), digital twin data (DD), service system (SS), connection (CN). Five-dimensional model separates the concept of digital twin data from the original three-dimensional model, and adds service system, fills in the gap of driving and changing in the digital twin system, satisfies the basic conditions of describing the dynamic working situation of the system, and creates the possibility of analyzing and establishing the digital twin system of multi-application scenarios. However, in practice, the theory of five-dimensional structure model is still too abstract to be directly used to guide the organization and construction of digital twin system.
On the basis of the digital twin five-dimensional model and the actual situation in software development and other related fields, we analyze the five elements of the digital twin system under dynamic operation, in order to establish a theory that can be used to directly guide the establishment and management of the digital twin system.

2. Element analysis of digital twin system in dynamic mode

In order to establish the topology of the digital twin system, we need to analyze the operation of the digital twin system. The theoretical model of the digital twin five-dimensional model is given, which satisfies the condition of analyzing and describing the dynamic working condition of the system. Firstly, we analyze the attributes of the five elements in the digital twin system.

2.1 Virtual entity (VE)

Virtual entity is the biggest feature of digital twin. The advantages of low cost and high flexibility of digital twin technology are concentrated on virtual entity. As an important carrier of twin data, virtual entity is the core of digital twin system in structure.

Virtual entities exist in the form of data, the most fundamental of which is the rule data mainly in three-dimensional space, while other data exist attached to the rule.

According to the definition of digital twin, virtual entity is the mapping of physical entity. But when the digital twin system works, from a dynamic point of view, the results of virtual entities need to be fed back to the physical entities to guide the physical entities to change. Therefore, in the digital twin system, the mapping between virtual and physical entities is bidirectional.

2.2 Physical entity (PE)

Before analyzing the physical entities in the digital twin system, we need to be clear: firstly, the purpose of the digital twin system is to create physical entities that meet human needs or to transform physical entities to meet human needs better; secondly, the digital twin system is a whole system including physical entities; thirdly, the digital twin system is a dynamic system.

According to the analysis of virtual entity, in the digital twin system, physical entity and virtual entity are two-way mapping, so when analyzing the concept of physical entity in the digital twin system, there is a question: in the digital twin system, physical entity and virtual entity which comes first, which is essentially the problem of the origin of virtual entity.

The application of BIM (Building Information Modeling) technology in construction industry also belongs to the category of digital twin system. In the process of BIM application, the design concept is transformed into three-dimensional model, and finally gradually into architecture. We define the entities that exist objectively in nature as real physical entities (buildings) and add the concept of vision physical entities (design concepts). Vision physical entities are the physical entities we expect to achieve, which also have data and attributes and can be reflected in virtual entities (three-dimensional models). In this way, the relationship between physical entity and virtual entity can
be described as follows: virtual entity comes from physical entity, part of which is the mapping of real physical entity, part of which is the pre-simulation of vision physical entity.

When the digital twin system runs, the verified vision physical entity transforms into the real physical entity, while the real physical entity that does not meet the requirements will be replaced by the vision physical entity in visual physical entity, then transformed into a new physical entity to realize the transformation of the real physical entity after verification.

Thus, we conclude as follows: in the digital twin system, physical entities are composed of real physical entities and virtual physical entities; the final object transformed of digital twin system is real physical entities; the real physical entities and virtual physical entities are dynamically transformed to form real physical entities products that tend to meet human needs through the verification of virtual entities.

![Figure 3. Composition of physical entities](image)

2.3 Service system (SS)
A service parameter is introduced into the digital twin five-dimensional model, which reflects the driving source of the operation of the digital twin system. Among the five elements of digital twin, service is the only active element and the only interference point for human beings in digital twin system.

The essence of service system is an operational judgment platform with input and output functions. There are two main purposes of service platform operation: inputting requirement and driving computer operation. Its workflow is: read data from external objects - form a database - make operational decisions - modify the database.

![Figure 4. Workflow of service platform](image)

As can be seen from Figure 2.3, the main function of the service is to read external data and operate the database through operation.

Each service platform has specific rules based on its functions, and the database it forms must conform to the corresponding rules. Strictly speaking, this database is also a virtual entity, which involves the concept of multiple virtual entities.

2.4 Connection (CN)
Physical entities, virtual entities and service platforms form the topological structure of the digital twin system by connecting. We call the physical entity, virtual entity, service platform and connection as the structural elements of digital twin system, among which physical entity, virtual entity and service
platform are called point structural elements.

When building a digital twin system, we need to pay special attention to what is connected at each end of the information channel, and whether the information channel is one-way or two-way.

2.5 Digital twin data (DD)
The operation of digital twin system is based on the flow and processing of data. To study and analyze the work of digital twin system is to study the flow and processing of data in a sense. In order to avoid the ambiguity of the word "twin" when analyzing the data running in the digital twin system, we define the twin data as all the data that exist and operate according to the rules defined by the system in the digital twin system.

System rules include rules that exist in real objects themselves and rules that are set manually which can be divided into natural simulation rules and computer operation rules.

In order to analyze the operation rules of twin data, we divide twin data into two categories: rule data and subsidiary data.

Rule data is the data representing rules in physical entities and virtual entities. Rule data are closely related to each other by topological logic. If we change rule data, we need to consider it as a whole. Because the logic is usually complex, it usually needs manual operation. The subsidiary data is the data stored in the prescribed position of the data structure, which only corresponds to the data structure. Changing the subsidiary data involving no other data in the same entity, which is usually relatively simple and easy to be modified by software algorithm. Generally speaking, spatial location and process rules belong to structural data, while attributes and subsidiary files belong to subsidiary data.

In the digital twin system, the point structural elements have their own structural rules, and the subsidiary data is stored in the prescribed structural position of the point structural elements. The service platform maps these data directly or after operation and transfers them to other point structural elements for operation and judgment. In this way, service elements drive the operation of the digital twin system.

In the digital twin system, the operation of twin data has the following characteristics:

Absolute incompleteness and relative completeness. It is impossible for a virtual entity to copy all the attributes of a physical entity, so the twin data it contains is absolutely incomplete. However, for the needs of specific service work interface, the data is complete and can finish related work. Therefore, when a service system with a certain interface needs to use twin data, it needs to collect relevant data, and other data is not related to it. Each specific service system does not need to acquire all the data, and each data does not need to be sent to all service systems.

Absolute asynchrony and relative synchronization. When the digital twin system runs, the data is retained in the physical entity and virtual entity, and processed in the service system. The data of the read-in end and the output end of the entity in the service system will inevitably be different, so the data will always be asynchronous in the whole digital twin system. The purpose of the digital twin system is to map virtual entities and physical entities through data synchronization. When a transformation cycle is completed, the entity data at both ends of the service reaches synchronization state. Therefore, the data in the digital twin system is always in a state of dynamic asynchrony in pursuit of synchronization.

3. Work interface assembly and multiple virtual entities

3.1 Work interface assembly (WIA)
Through the analysis of the five elements, we can find that isolated physical entities or virtual entities can only be static and unchanged, and only when driven by service elements can they change. Therefore, in a digital twin system, physical/virtual entities must be combined with service elements.

The drive of service elements to physical/virtual entities is based on the specific rules between them. In the digital twin system, physical or virtual entities must combine with service platform to form a work interface assembly under certain working rules. The working rules between specific
physical/virtual entities and specific service platforms must satisfy both data storage structure and service purpose of physical/virtual entity.

In the work interface assembly, physical or virtual entities are only the storage points of data, while service platform is the driving source of data, which actively reads/writes data from/in physical/virtual entities. Unlike physical entities, it is very difficult to fully grasp the rules of existing virtual entities. Therefore, in practical applications, virtual service platforms need to form specific virtual entities to write data. Thus, the service platform responsible for writing data determines the rules of virtual entities, while other service platforms can only read data according to the rules of data storage structure of virtual entities. That is to say, a virtual service platform must be tied together with the formed virtual entity which can only write data by the virtual service platform. Based on the exclusiveness of virtual service platform for virtual entities, a set of virtual service platform + virtual entities is formed, which we call virtual work interface assembly. Further, we define the work interface assembly, which consists of an entity and a service capable of editing the entity.

![Figure 5. Work interface assembly of virtual entities](image)

Similarly, physical entities and corresponding service platforms form a work interface assembly. However, the rules of physical entities are not exclusive, and can form multiple work interface assemblies with multiple service platforms.

### 3.2 Multiple virtual entities

In the digital twin system of a single physical entity, there is a physical work interface assembly centered on physical entities. The physical work interfaces act on physical entities directly, the write-in function of which is basically realized by manual work at present. When the digital twin system needs to achieve multiple functions, it needs multiple virtual service platforms, and there must be multiple virtual entities and virtual work interfaces. At this point, the relationship between the virtual work interfaces is as follows:

![Figure 6. The formation of multiple virtual entities](image)

As you can see, the data information of some virtual entities comes from other virtual entities. We define the virtual entity that maps data directly from physical entity as the native virtual entity, the data contained in which is the primary twin data. The virtual entity mapped data from other virtual entities is defined as the secondary virtual entity. According to the hierarchical level, the virtual entity is divided into the Lv.1 secondary virtual entity, the Lv.2 secondary virtual entity and so on. Then we
get the concept of multiple virtual entities.

4. Topological structure of digital twin system

4.1 Tree topology of digital twin system

Based on the above analysis, the topology of the digital twin system is illustrated as follows.

![Topological structure of digital twin system](image)

Figure 7. Topological structure of digital twin system

From the mapping relationship of virtual entity model, the topological structure of digital twin system is a tree structure.

In this structure, physical entity and primary virtual entity are unique, and secondary virtual entity can have multiple hierarchical structures. The mapping direction of the model is irreversible downward step by step.

4.2 Data flow in a tree topology

In the tree topology structure of digital twin system, the main flow of modeling data is physical entity-native service modeling platform-native virtual entity-secondary service modeling platform-secondary virtual entity. Among them, native service modeling platform generally needs a lot of manual operations at the present stage. Secondary service modeling platform generates secondary virtual entities by mapping native virtual entities based on rules, which requires less manual intervention.

One of the most noteworthy is that when the secondary virtual work interface gives feedback and needs to change the structure of the secondary virtual entity of the work interface, the information needs to be fed back to the native virtual entity work interface, which can be achieved by modifying the native virtual entity. The direct reason is that secondary virtual entities are mapped and do not have the attributes of editing modification. More importantly, in order to maintain the uniqueness and unity of data in the whole digital twin system, it is necessary to modify the virtual entities from the original data of modeling.

5. Summary and prospect

5.1 Some principles and concepts of digital twin system

Through further dynamic analysis of the working status of the digital twin system and observation and discussion of the working status of the structural elements of the digital twin system, a series of principles and concepts that must be followed in establishing and managing the operation of the digital twin system can be summarized.

- Digital twin system is a dynamic system. In the digital twin system, data is not exactly the same "twin" state as literal. Instead, it promotes the optimization of digital twin system by running the cycle of "asynchrony-synchronization-asynchrony".
Physical entity is composed of two parts: vision physical entity and real physical entity.

In digital twin system, service element is the only drive of system operation and the only entry point of human interference.

In the digital twin system, neither physical entity nor virtual entity has initiative. Physical entity and virtual entity must be combined with service system and exist in the form of work interface assembly.

In the digital twin system, each application function is distributed in the work interface assemblies.

In the digital twin system, each work interface assembly contains the data to realize their own application functions. The data content in each work interface assembly is not completely consistent.

The work interface assembly can only read information data outside the work interface, but not write data to the outside.

The native virtual model is the total data source of the virtual model of the whole digital twin model. Secondary virtual models are generated by mapping native virtual models.

When using virtual entity to build digital twin system, we should consider service but virtual entity as the center. In order to realize the application function, service is needed first, and then virtual entity is constructed with service elements as the center, which forms a work interface assembly and realizes the application function.

When building a digital twin system, a corresponding work interface assembly needs to be built for each application function.

Manual operation is unavoidable, and the establishment of digital twin system cannot completely replace manual work. Manual operation only exists in service elements, which can be divided into two categories: first, the development of artificial intelligence has not met the requirement, and some operations can only be completed by human; second, computer can be used to replace manual work, but no corresponding software has been developed.

5.2 The main problems affecting the operation of the digital twin system and their solutions

From the above analysis, we can see that the digital twin system in operation is a dynamic system. Its topological structure is not constructed randomly, and the data flow among the units of the topological structure is restricted by many factors. To solve the problem of data flow, the more complex the digital twin system needs more service platforms, while a large number of service platforms will produce a large number of manual operation links, which will reduce the system operation efficiency, resulting in a gap with the expected effect. In some cases, this gap can affect the practical application of digital twin projects.

It can be said that the number and complexity of manual intervention steps determine the vitality of digital twin system.

Based on the previous analysis, we propose to start from the following two aspects:

Reducing the first kind of manual operation links limited by the development level of artificial intelligence.

According to the topological structure of digital twin system, this kind of operation mainly comes from the modeling operation of native virtual entity. As the modification of structural data is involved, it is necessary to return to the source of the original virtual entity for operation. Therefore, the modeling and modification of the native virtual model occupy a large part of the human labor in the operation of the digital twin system. When planning and establishing the digital twin system, we should make clear the various functions that need to be achieved by digital twin, ensure the important functions, reduce the unnecessary functions and reduce the number of functional platforms to simplify the amount of data that the native virtual model needs to contain, so as to reduce the difficulty of modeling, thus greatly reducing the labor workload.

Developing software to replace the second type of manual operation
The digital twin system involves many service platforms, which also means many professional departments. The manager of digital twin system should coordinate all departments to classify the second kind of manual operation and develop corresponding software to replace it.

6. Conclusion
Twin system has great practical value. Its development has gone through the stages of twin, system and digit. The concept of digital twin has been given great expectation since it was put forward, but it is far away from people's expectation in practical application.

Under the theory of five-dimensional model, by analyzing the digital twin system dynamically and summarizing the operation rules of the digital twin system, we can conclude that the main problem of the operation of the digital twin system at present is the need for a lot of manual operations.

To solve this problem, we should fundamentally solve it from the planning and construction of the system: first of all, we need to overcome the idea of being all-inclusive and one-step when establishing the digital twin system, and we must avoid to have extremely high expectations but reasonably select the important functional objectives to be achieved and discard the unnecessary functional objectives; second, we need to coordinate the functional implementation departments and develop the corresponding manual operation software.

Like other software platforms, the application of digital twin system is fundamentally inseparable from human management. In order to play its due role, a digital twin system should be established and operated in a proper management mode.

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