Title:
STEP-based digital twin model construction for assembly

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Introduction:
The digital twin (DT), one of the key theories in the field of next-generation digital manufacturing, is beginning to demonstrate its important role in the product assembly process. In order to research the phenomenon of unstable product performance due to assembly, it is necessary to construct a digital twin- driven assembly model. However, the modeling approach of assembly digital twins is not comprehensive due to the existence of a large number of multivariate heterogeneous data, which hinders the analysis and simulation in assembly process. In this paper, a STEP-based digital twin modeling method for assembly is proposed. By analyzing the attributes of the components, tooling systems, and measurement systems involved in the assembly process, as well as the interrelationships between them, the existing physical models are expanded and redefined as necessary. A data model in compliance with the STEP standard is proposed to facilitate the exchange and unified analysis of various resource data during the assembly process.

Main Idea:
The assembly digital twin is a further development of the virtual-physical fusion assembly technology [1]. Based on the virtual assembly information model for predicting assembly quality, the digital twin data of assembly context is used to realize the virtual-real interaction, data fusion, quality analysis and iterative optimization of the whole assembly process. The concept of the digital twin was first proposed by Gieves [2] to describe the actual physical entity through a set of virtual information structures. To achieve this, a digital twin model that enables communication between the physical and virtual worlds needs to be built. Several studies have investigated digital twin modeling approaches, developing a more realistic five-dimensional model [3] based on the three-dimensional digital twin model defined at the beginning. However, most of the current research on digital twin assembly is a theoretical framework. In order to break the barrier between theory and real-life applications, there is an urgent need for a standardized data structure to store or exchange the data generated during the assembly process.

Assembly digital twin model framework:
In order to adapt to most assembly modes, based on the mapping relationship between virtual assembly space and physical assembly space, the theoretical framework of digital twin-driven assembly process is established [4], as shown in the Fig.1. The model mainly includes four spaces: physical, virtual, data and service. The division of the four units is mainly to maximize the data value of the assembly unit and help the exchange of heterogeneous data streams between platforms. The definition of four-dimensional assembly unit is as follows:

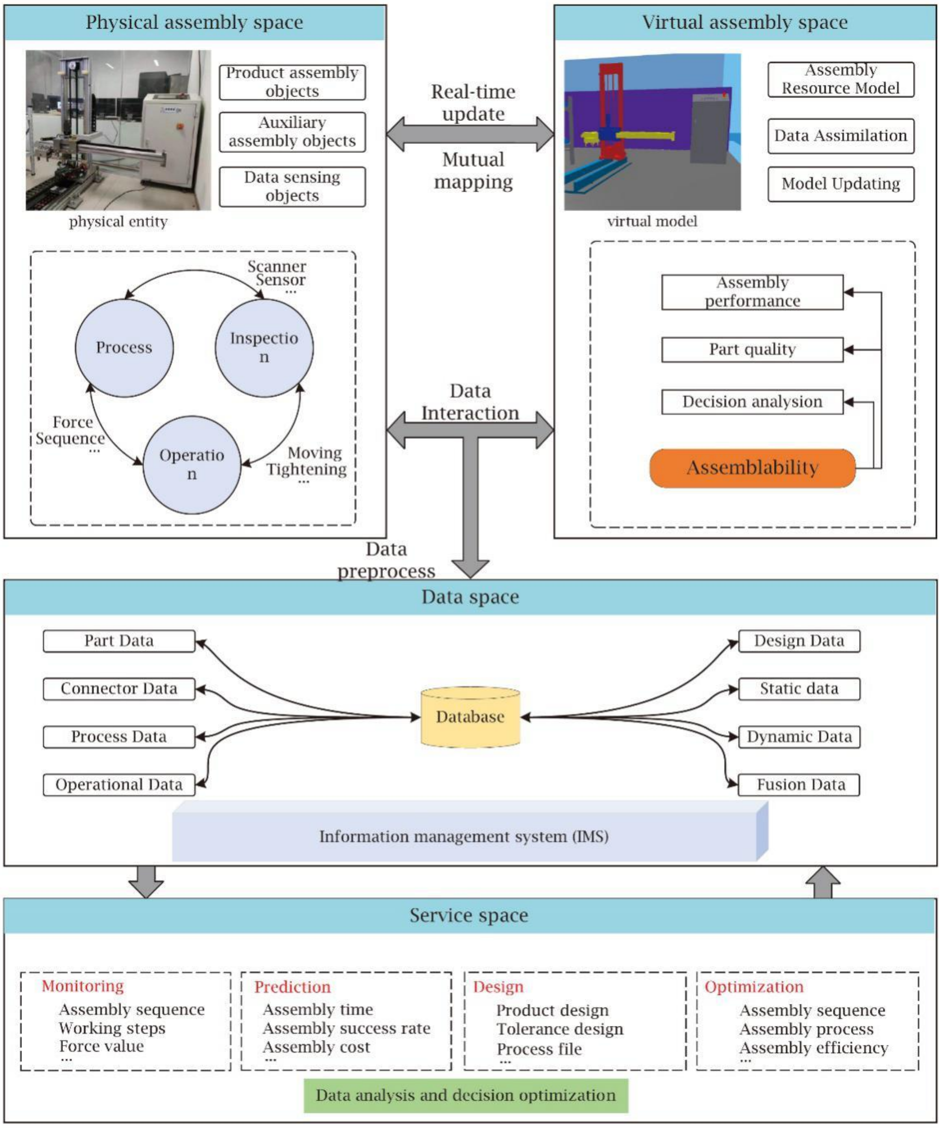

Fig. 1: Digital twin assembly model.

- Physical space: The physical space is a collection of physical resources for on-site assembly, and this process is combined with inspection to reflect the specific state of each component in the actual assembly process, and the data obtained from the inspection is transmitted to the digital twin data center.

- Virtual space: The virtual space is a mapping of the physical resources of the field assembly in the virtual space, driven by data.

- Data space: Data space is an abstract dimension that contains data from various sources involved in the assembly process, both multi-sensory data in physical space and model data defined in virtual space, which is the core component of the entire DT.

- Service space: The service space is used to manage and analyze the data and is directly connected to the data space, providing in and out functionality for the data generated by the digital twin model, while analyzing and extrapolating this data to enable monitoring of the physical assembly process and prediction of the quality of the assembly. Moreover, it also can provide possible optimization solutions for the assembly process.

The connection and collaboration between these different modules empower the assembly digital twin model to monitor and sense. It can be seen that a large amount of heterogeneous data exists between different systems and modules during the construction of the assembly digital twin model, so it is necessary to establish a standardized format for data exchange. In this paper, we consider a complete data structure definition based on STEP for the structural characteristics of the assembly digital twin model in order to promote the further development of the assembly digital twin technology.

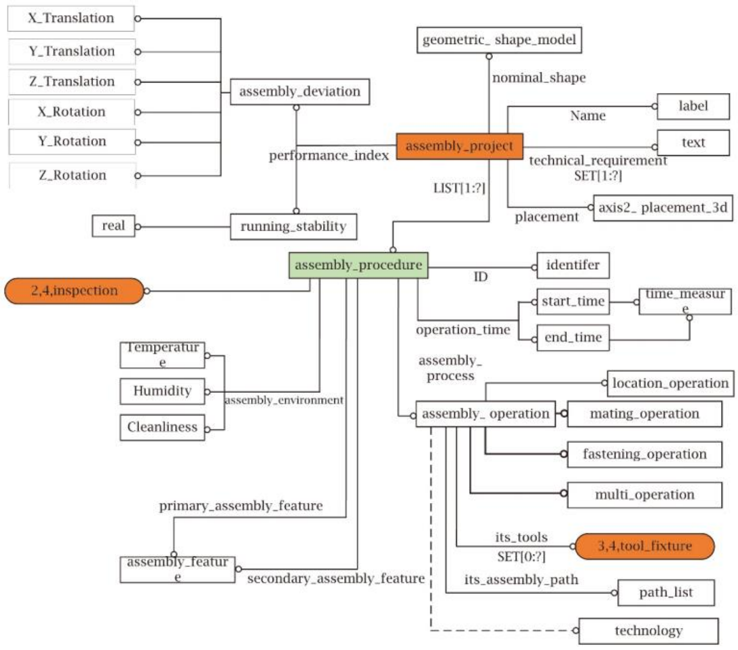

Fig. 2: EXPRESS-G representation of the assembly model.

STEP scheme for assembly digital twin model:
The STEP standard involves the establishment of an explicit representation and exchange mechanism for computer-interpretable product information throughout the product lifecycle, expressed in a three-layer structure, including a reference model, a format object class and pattern definition language EXPRESS, and physical communication (file structure) [5]. In this research, for the characteristics of data flow in the assembly digital twin model, a three-part structural model is established for the representation of the assembly data, which are the assembly layer, the tooling fixture layer and the inspection layer. By applying STEP as the information model and the assembly digital twin model scheme as the integration model, thus achieving the integration of assembly information between the structural models. Define a generic assembly twin data model using the EXPRESS language, which can inherently integrate object- oriented structures into new data structures. The defined assembly digital twin model is embedded in the AP203 standard, this research selects the entities defined in STEP, ISO 10303-203, ISO 10303-21, ISO 10303-42 and ISO 10303-47, etc. On this basis, it is described as product definition data for the assembly process by inheritance, combination and extension. Based on the previous discussion, the details of the definition of the STEP-compatible model for assembling digital twin models are described as follows.

- Assembly model: In the actual assembly process, the assembly is completed according to the assembly process guidance. The assembly process is usually based on the assembly task-assembly process-assembly step hierarchical structure, and the data involved in different levels are different, so it is necessary to analyze the description objectives of each level and build the assembly model. The entities directly contained in the assembly model include *Nominal Shape*, *Performance index*, *Assembly procedure* and *Technical requirement*. The entity *Nominal Shape* describes the 3D design model of the assembly, the entity *Performance index* describes the assembly performance metrics parameters, including the geometric deviation and running stability of the assembly, the entity *Assembly procedure* represent the components of assembly procedures, including the duration of the assembly procedure. the entity *Technical requirement* contains the technical requirements of the assembly. Specific details are shown in the Fig.2

- Tooling fixture model: This scheme is to assist the assembly, and its clamping quality is directly related to the assembly quality, so it is included in the assembly digital twin model. This group contains four entities, *Nominal Shape*, *type*, *Operation specification* and *System accuracy*, represent the geometric model of the tool or fixture, the function of tooling or fixtures, the operation requirements of using the tool and fixture, the object to be faced and the accuracy grade of the system respectively. As shown in the Fig.3.

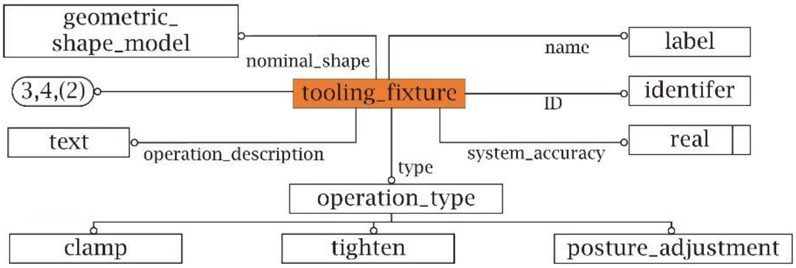

Fig. 3: EXPRESS-G representation of the Tooling fixture model.

- Inspection: In order to ensure the product assembly quality, in the process of digital assembly, a large number of inspection equipment is needed to inspect the assembly parts and key nodes in the assembly process. The inspection process is characterized by the diversity of inspection tools and inspection contents, and there may be additional inspection contents for different assemblies. According to these characteristics, the detection group is divided into *Measurement equipment* and *Measurement content* entities. They respectively represent the equipment used in the inspection and the inspection contents. The general inspection contents include geometric shape inspection, mechanical performance inspection and assembly environment inspection respectively. As shown in Fig.4.

So far, the main frame and content of the assembly digital twin are completed.

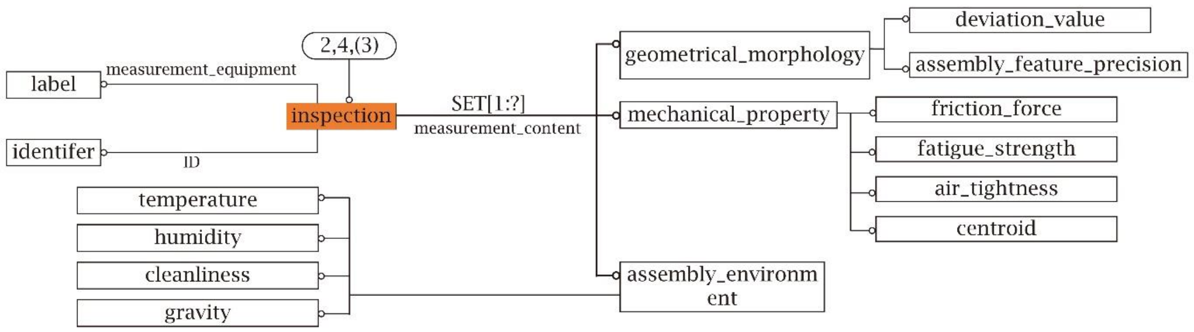

Fig. 4: EXPRESS-G representation of the Inspection model.

Conclusions:
At present, in the field of assembly digital twin technology, there is no unified standard for the needs of data acquisition and exchange. The original standard of STEP contains a wealth of geometric and process definitions, and has certain advantages in terms of technical maturity and scalability. This paper addresses the issue of standardizing data for assembling digital twin models and proposes a unified data model that can be flexibly defined for different types of products and allows data to be easily passed across applications throughout the system.

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