Research on Construction Method of Digital Twin Workshop Based on Digital Twin Engine

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***Abstract*—The concept of the virtual workshop has been proposed for many years, and many companies have built their own virtual workshops for planning and simulation. But only virtual workshop cannot realize the interaction of the physical world and virtual world required for smart manufacturing. The digital twin workshop is a useful way to realize the fusion of virtual workshop and physical workshop, and optimizes the activities. This paper studies the concept of digital twin workshop, and digital twin workshop is divided into three parts: virtual workshop, physical workshop and digital twin engine. At the same time, this paper emphatically analyzes the definition and function of the digital twin engine in the digital twin workshop system, and also proposes an architecture for building the digital twin workshop based on the virtual workshop models. Finally, taking the implementation of digital twin workshop of an intelligent manufacturing unit as an example, the effectiveness and functionality of the digital twin workshop of an intelligent manufacturing unit are verified based on the digital twin engine.**

***Keywords*—Digital twin, Virtual workshop, Digital twin workshop Digital twin engine**

I. Introduction

The virtual workshop model is diffusely used in various scenarios in various enterprises such as workshop planning and simulation, and the typical applications include logistics simulation, and factory layout simulation. Through virtual simulation, we can preview the pivotal elements of each stage of the workshop life cycle, find out the design problems of the workshop in advance, and reduce the changes of the design scheme in the construction process of workshop. However, the virtual workshop based on geometric models can not reflect the interaction and co-fusion of the physical world and virtual world needed by intelligent manufacturing. An important characteristic of digital twin is the connection of physical and virtual worlds, which unifies the virtual and real worlds to realize the closed loop between production and design. Therefore, digital twin is a useful way to implement the virtual-real fusion of workshop and intelligent optimization management [1-2].

The notion of digital twin(DT) was first proposed by Grieves in the course of product life cycle management in 2002, which is called PLM concept ideal model. It has all the elements of digital twin: real space, virtual space, and data flow connecting real space and virtual space. The premise of the concept of digital twin was the existence of physical systems and virtual systems, and virtual systems contain all the information of physical systems [3]. At present, the concept and frame of digital twin has been verified and applied in many fields. Siemens' digital twin includes "product digital twin", "production digital twin" and "performance digital twin", which are highly integrated into a unified data model [4]. The US Air Force Research Center has predicted the life of aircraft structures based on DT and summarized the technical advantages of DT [5].

The workshop is a place for daily production and manufacturing activities. How to apply digital twin technique to the workshop level is the focus of many scholars and enterprises. Tao Fei et al. proposed the concept of digital twin workshop, and designed the reference architecture of the digital twin workshop system. At the same time, from the perspective of the composition of the digital twin workshop, the key issues such as the heterogeneous elements fusion in the physical workshop, the multidimensional model fusion of the virtual workshop, and the workshop physical-data fusion, workshop service-application fusion have been studied and analyzed, which provides a reference architecture for enterprises to realize the digital twin workshop [6-7]. The key to the digital twin workshop is to implement the interaction and fusion of the virtual workshop and the real workshop, and how to provide intelligent services for the workshop managers. The basis of integration of virtual workshop and physical workshop is data collection and fusion. Data is the foundation of the construction of the digital twin workshop. Downey et al. have carried out research on the analysis of the complex data from the sensors and real-time production data collection [8]. In the fusion of sensor data and manufacturing data, Yi et al. have conducted the theoretical study on the requirements of digital twin data fusion [9]. Intelligent service is the final purpose of the digital twin workshop, such as equipment fault diagnosis, production process prediction and real-time logistics planning guidance. Although many studies have been carried out on the DT technique and the concept of digital twin workshop, there are still some problems: 1) Most of the research all emphasized the importance of virtual-real fusion and intelligence but there is a lack of clear design and analysis on the implementation of architectures of virtual and physical workshop connection and providing intelligent services; 2) The roles of the components of the digital twin workshop system are not clear.

Based on the problems mentioned above, this paper studies the construction method and frame of the DT workshop based on the DT engine, and proposes the architecture of the DT engine to realize the DT workshop.

978-1-7281-6521-9/20/$31.00 ©2020 IEEE

Dalian, China•August 25-27, 2020

II. Digital Twin Workshop

Based on the above analysis, the DT workshop can be defined as a virtual-real fusion workshop system with intelligent decision-making ability based on the virtual workshop that accurately maps all elements of the physical workshop, which is combined with intelligent algorithm models. In the digital twin workshop, a new generation of information technologies are used to realize bidirectional and real-time interaction mapping between the real workshop and the virtual workshop.

The DT workshop emphasizes the coordination and unification of physical and virtual workshops, and provides various intelligent analysis and prediction services based on intelligent algorithms. Therefore, the DT workshop has two important models. The first is the real-time connection module between the physical and virtual workshops; the other is the intelligent computing module.

This paper finally defines the real-time connection between the physical and virtual workshops and the intelligent computing module as the DT engine. In order to realize intelligent perception of the physical workshop in the DT workshop system, the physical workshop needs to have digital access capabilities, so the DT workshop system is finally divided into three parts, including the digital physical workshop, virtual workshop and DT engine. The DT workshop system is shown in Figure 1.

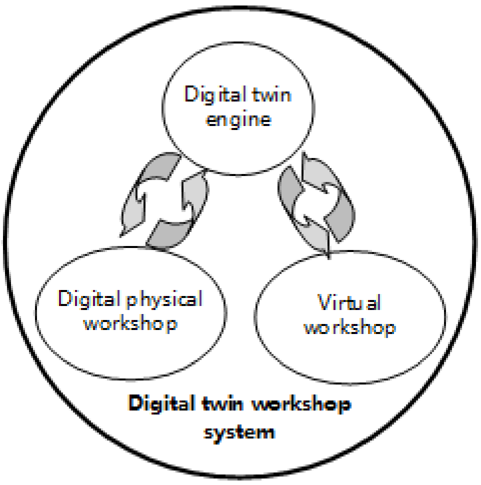

Fig.1. The compositions of digital twin workshop system

Based on the above analysis, the architecture of the DT workshop system is designed and shown in Figure 2, which includes the system layer and function layer. The system layer is composed of three subsystems (digital physical workshop, DT engine, virtual workshop) of the DT workshop system; the functional layer contains functions that the subsystem services ultimately provide. It can be seen from the architecture of the DT workshop system that the DT engine is the key to realize the virtual-real fusion between the digital physical workshop and the virtual workshop, and it is also the core of realizing system intelligence.

On the one hand, the DT engine is the driving engine that realizes the real-time synchronization between the digital physical workshop and the virtual workshop. On the other hand, it is the core of the intelligent algorithm and intelligent computing engine of the DT workshop and provides advanced intelligent services for production management personnel. With the support of the DT engine, the DT workshop can implement the virtual-real interaction drive and provide various intelligent functions.

As previously analyzed, the DT engine can be divided into interactive driving and intelligent computing functionally. As shown in Figure 2, according to the system's functional characteristics, the functional modules of the DT engine can be divided into the data interaction module, the data ETL module, the data storage module and the data analysis module.

a) The data interaction module: The data interaction module is mainly composed of various interaction interfaces, mainly including the interaction interface with the digital physical workshop, the interaction interface with the virtual workshop and the interaction interface with external systems;

*b) The data ETL module:*Due to the diversity of workshop equipment and the large differences in data structure between different equipment, there are problems such as multi-source heterogeneous data and invalid data. The data ETL module mainly aims at solving these problems by extracting, cleaning and loading workshop data to obtain reliable data that can be directly used for analysis;

*c) The data storage module:*The data storage module is mainly aimed at the data diversity of manufacturing workshop, in which the storage characteristics of structured data and unstructured data are different, so different storage methods should be adopted according to the characteristics of workshop data;

d) The data analysis module: The data analysis module utilizes data mining, machine learning, large data software and other related technologies to realize the analysis of the workshop information, exploit the valuable data of the workshop, and convert it into knowledge models to serve the workshop;

III. Implementation Architecture of Digital Twin Engine

This paper divides the implementation architecture of the DT engine into three layers, including the data layer, the calculation engine layer and the model layer to specifically implement the DT engine, as shown in Figure 3.

A. Data layer

Data layer is the basis of workshop large data storage, which is mainly composed of data preprocessing and data warehouse.

Data warehouse is the storage warehouse of workshop large data and the data base of DT engine. Because the amount of data in the workshop is very large, a stable distributed database is required to meet the data storage requirements. At present, the distributed data warehouse mainly includes HDFS, HBase, MongoDB, Impala, etc. HDFS is a large-scale distributed file system, which has the characteristics of high availability, large storage capacity and diverse storage format, and meets the needs of large data storage in the workshop. Meanwhile, HDFS system is the bottom layer dependence of hive data warehouse, which has good support for offline analysis.

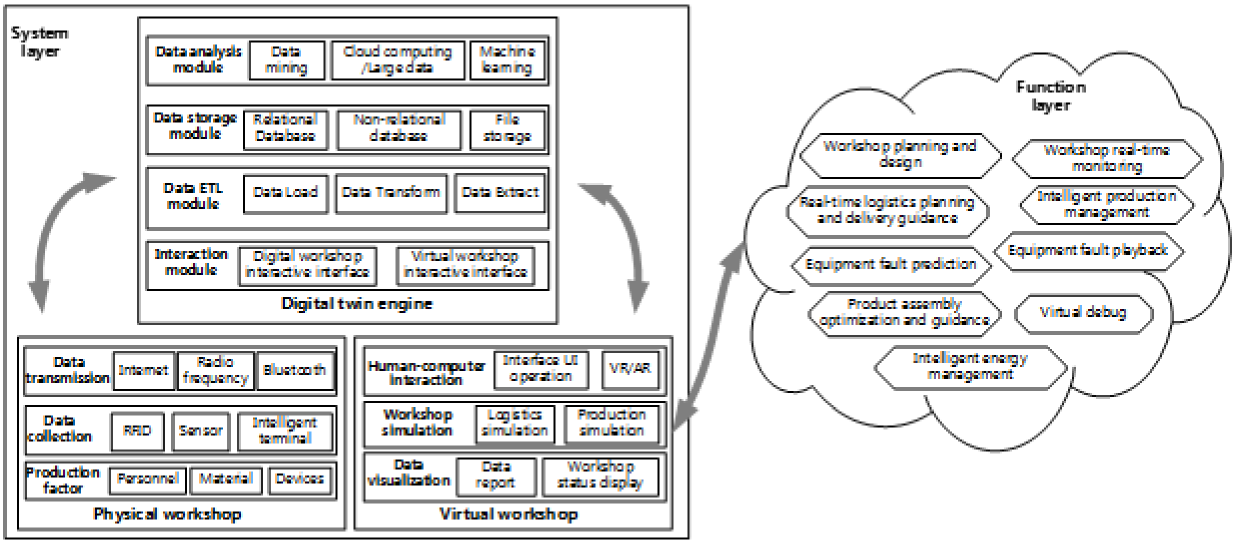

Fig.2. The digital twin workshop system

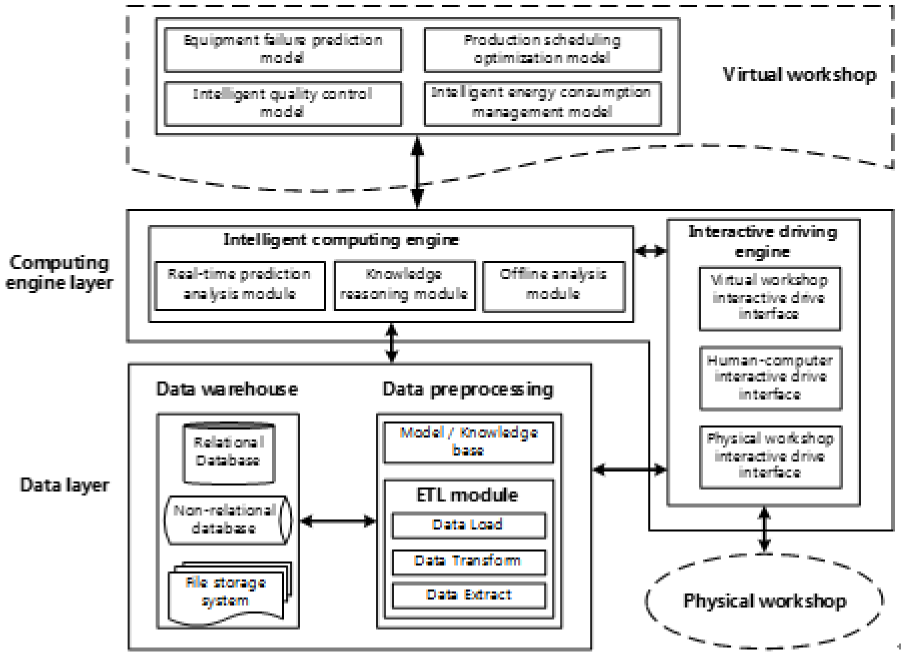

Fig.3. The implementation architecture of digital twin engine

Due to the diversity of data warehouses, there are also different requirements for data, so the data collected through different data collection protocols needs to be processed through specific processing before it can be stored in a specific data warehouse. This process is called ETL (Extract-Transform-Load). The ETL process can be divided into three stages: (1) Extract useful data that can be analyzed from the data source. (2) Transform the data so that the data meets the structure of the subject warehouse, and use data cleaning and data purification processes to ensure the quality of the data converted; (3) Load the quality-assured data which is transformed into the target data warehouse.

The highly available and persistent features of the data warehouse provide data support for the subsequent work of the DT engine.

B. Computing engine layer design

The computing engine layer is the computing center of the DT engine. Based on the data provided by the data layer, the algorithm models are trained through many intelligent algorithms to provide support for the model layer. The computing engine layer is mainly divided into two parts, the intelligent computing engine and the interactive driving engine.

The intelligent computing engine is mainly divided into three modules, including offline analysis module, real-time prediction analysis module and knowledge reasoning module.

The offline analysis module is mainly used for workshop data analysis and model training. The main technologies include the mainstream large data framework Hadoop and Spark. Both Hadoop and Spark can process large amounts of data in a distributed manner. Using big data analysis technologies such as Hadoop and Spark can easily deal with the application scenarios of large data analysis in the workshop, and can analyze workshop data statistically in different dimensions according to user needs. At the same time, Spark MLlib is a packaged machine learning library. The DT engine can easily achieve the purpose of model training by calling the package. Hive and Impala are also distributed and highly available, and support simple SQL queries friendly, so in the offline analysis layer, you can also use this type of database for offline analysis of workshop data, such as workshop data reports.

The real-time prediction analysis module serves the prediction and analysis functions of the workshop. The large data frameworks such as Spark Streaming, Flink, and Storm have the characteristics of real-time and high availability in real-time online analysis, which can easily meet the needs of real-time analysis of big data in the workshop. At the same time, the real-time computing framework will combine the prediction models trained in the offline analysis stage for real-time analysis, and inform the DT workshop system of the prediction results in advance, so as to make the next intelligent production decision.

The knowledge reasoning module mainly refers to the module that the system realizes the rapid reasoning function based on the knowledge base, effectively promotes the solution of the problem, and realizes better intelligent production.

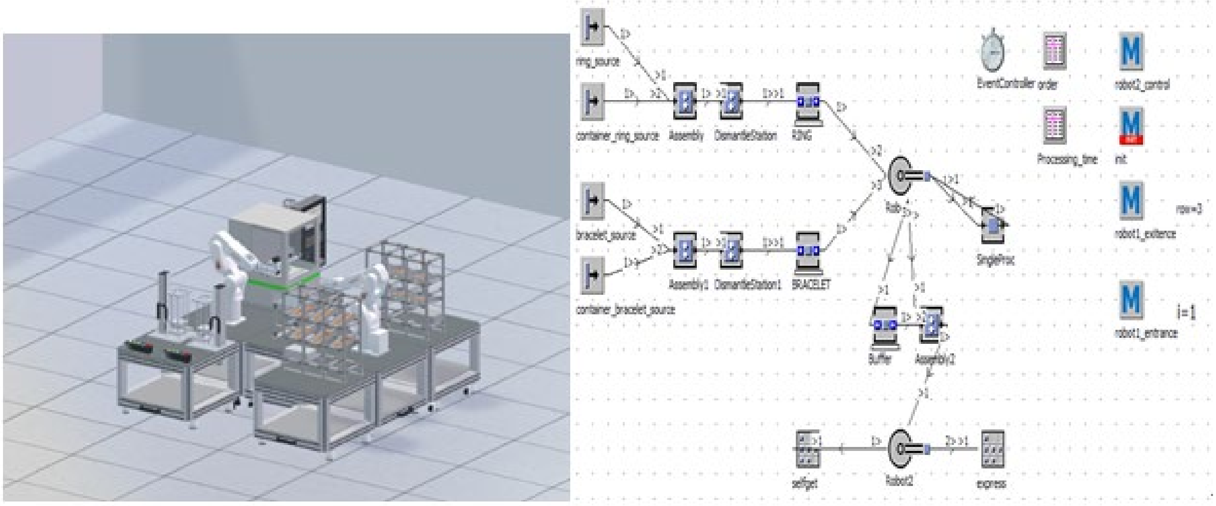

Fig.4. Virtual model of the intelligent manufacturing unit

The interactive driving engine is an interactive synchronization tool between the virtual workshop and the physical workshop. The DT engine is the center between the virtual workshop and the physical workshop to realize data interaction, virtual-real synchronization, and the issuance of production management and control instructions.

IV. Case Study

In this section, the construction architecture of the DT workshop based on the DT engine is verified by taking an intelligent manufacturing unit as the research object. Based on the physical part of the intelligent manufacturing unit and the virtual model of the manufacturing unit, the DT intelligent manufacturing unit is finally realized through the implementation of the DT engine.

A. Introduction to intelligent manufacturing unit

*1) Physical part of the smart manufacturing unit:*The physical part of the intelligent manufacturing unit mainly includes the physical environment, production equipment and communication equipment. The production equipment includes two production robot arms in the production unit, a laser engraving machine of the numerical control system, a transfer table, an automatic lifting table, and two warehouses. The communication device mainly refers to the access device iBOX used to control device data collection and communication. The device can collect parameters of the machine tool equipment in real time, such as the real-time joint angle of the robot arm, etc. The parameters and frequency collected can be configured according to specific requirements. In addition, the information exchange process with the cloud MES system is also completed through iBOX.

The key parameters of this system, such as the status information of the robot arm, the status data of the engraving machine, and the status information of the warehouse, etc., can be obtained from the cloud MES through the WebService interface, which is the basis of the implementation of the DT unit.

*2) Virtual model of intelligent manufacturing unit:*The virtual models of the manufacturing unit are developed based on the Unity and Plant Simulation platform, which mainly includes two parts: the three-dimensional interaction model and the logistics model, as shown in Figure 4.

The three-dimensional interactive models are developed based on Unity, and the logistics model of production unit is constructed based on Plant Simulation. The three-dimensional interactive models are mainly used for production simulation of the intelligent manufacturing unit, including three-dimensional virtual model and virtual device action model. The logistics model of the production unit is mainly used for logistics simulation of the intelligent manufacturing unit, and the three-dimensional virtual model can be driven by the logistics model to realize the three-dimensional logistics simulation. Therefore, without the support of the DT engine, the virtual model and physical part of the intelligent manufacturing unit exist independently of each other and there is no interactive feedback between the virtual model and physical part, so that coordination and unification between the physical part and virtual models of the intelligent manufacturing unit cannot be achieved.

B. DT Manufacturing Unit

The DT workshop system based on the DT engine framework is shown in Figure 5.

The services of the DT intelligent unit mainly include real-time monitoring, offline simulation, unit evaluation and VR roaming.

Fig.5. Digital twin intelligent manufacturing unit

The DT workshop system monitors the real-time status of equipment and manufacturing and production information through the real-time monitoring function. The real-time status of equipment is obtained from the equipment in the manufacturing unit through the DT engine. The production information is obtained from the cloud MES via the web service interface, and then the digital monitoring is carried out in the virtual environment of the intelligent manufacturing unit.

Offline simulation function mainly includes machining process simulation and logistics simulation. The machining process simulation comes from the virtual manufacturing unit's own built-in functions, and the logistics simulation is obtained through the interaction between the DT engine and the logistics simulation software Plant Simulation.

The unit evaluation function mainly includes equipment health evaluation and KPI evaluation, which can be calculated and analyzed by combining production and equipment data with algorithm models.

VR roaming function, the virtual manufacturing unit uses HTC VIVE to realize virtual reality technology, and provides workshop roaming function and the function of interactively obtaining device information through the handle.

V. CONCLUSION

The DT workshop based on the DT engine solves the problem of the isolation between the virtual workshop model and the physical workshop, and achieves the purpose of coordinating and unifying the physical workshop and the virtual workshop. At the same time, based on the analysis and application of big data, the DT workshop can provide better intelligent services. This paper proposes the notion of the DT engine based on the architecture and implementation process of the DT workshop, and regards it as the service and driving center of the DT workshop. Finally, the intelligent manufacturing production unit is used as an example to verify the effectiveness of the implementation of the DT workshop, but more researches are needed on how DTs can better provide intelligent services in the DT workshop system.

ACKNOWLEDGMENT

This work in this paper is supported by the Key Fund of Shanghai Science Technology Committee No.19DZ1206800, Shanghai Artificial Intelligence innovation and development project (NO.2019-RGZN-01024) and 2018 industrial Internet innovation and development project from MIIT (The construction of the industrial Internet platform test bed for manufacturing business process optimization by network collaboration).

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