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MANUFACTURING PROCESS ORIENTED 3D VIRTUAL MONITORING SYSTEM FOR WORKSHOP

C. ZHOU[1] J. LI[2] L. K. JU[3] AND K. T. SUN[2]

ABSTRACT

In view of the high development threshold, poor applicability, and low development efficiency of the current manufacturing workshop virtual monitoring system, an industrial Internet of Things platform is proposed as a data application bus, which consists of the physical layer, twin layer, platform layer, application layer, and network layer. Firstly, the key technologies of workshop 3D virtual monitoring are described, including virtual scene construction, data acquisition and real-time data mapping based on industrial Internet of Things platform. Secondly, in view of the difficulty of data acquisition in the workshop, a twin data acquisition method based on industrial Internet of Things platform is proposed. Finally, taking the seal production workshop as the application object, the 3D virtual monitoring system of the seal production workshop is designed and developed. The results show that the workshop 3D virtual monitoring system has good real-time performance and realizes multi-level and visual monitoring. It has a certain reference value for the development of workshop 3D virtual monitoring system.

KEYWORDS: Monitoring system, Industrial internet of things platform, Geometry modeling, Data acquisition, Real-time data mapping.

1. INTRODUCTION

With the development of information technology and the continuous progress of industrialization, the level of automation and informatization in manufacturing industry is constantly improved. More and more manufacturing enterprises are engaged in production and manufacturing activities in the way of automatic production line. A large number of automatic production lines put into use can meet the production of large quantities of products, significantly improving the economic benefits of enterprises.

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[1] Ph. D. Candidate, School of Mechanical Engineering, Nanjing University of Science and Technology, China.
[2] M. Sc. Candidate, School of Mechanical Engineering, Nanjing University of Science and Technology, China.
[3] Associate Professor, School of Mechanical Engineering, Nanjing University of Science and Technology, China, jwcjlk@njust.edu.cn.

However, on the one hand, due to the low level of information management, enterprises lack of fast and effective means to manage and monitor the operation of the workshop; on the other hand, there are various management systems on the market. There is no effective means of information interaction between management systems and control systems, so the transparency of production process is difficult to achieve.

In recent years, the workshop 3D virtual monitoring system based on real-time data-driven has attracted much attention. Many scholars at home and abroad have carried out research and practice on it and achieved certain results. However, there are common problems such as high threshold of system development, low development efficiency, poor portability and single monitoring mode.

In 2005, the researchers [1] developed a remote monitoring system for small and medium-sized enterprises, which used 3D hierarchical information visualization environment as the interactive interface of the monitoring system. The monitoring and diagnosis system of press production line which provides remote online monitoring, diagnosis function and media playback function was developed in 2008[2]. Aiming at the problems of backward management, information lag and low visibility of manufacturing workshops, some scholars [3] analyzed the problems faced by the visual monitoring of production workshops and studied the key technologies of visual monitoring of production workshops. Finally, they defined the object data model, visual representation model and user interaction model of visual object model technology. The implementation technology of visual dynamic monitoring of workshop production execution based on Flexsim was proposed in 2013[4]. Some scholars [5] designed a real-time monitoring system for manufacturing workshops based on the analysis of the current situation of workshop monitoring and the data types of discrete enterprise workshops. A real-time data acquisition and visual monitoring method for discrete manufacturing workshops based on radio frequency identification technology was proposed [6]. Some researchers [7] studied the intrusive 3D real-time monitoring system for digital workshop and established the demand framework, architecture and operation mode of the monitoring system. Some researchers [8] established a workshop status monitoring system based on virtual reality technology and information integration technology and realized real-time monitoring of the location and status of personnel, materials, equipment, etc. in the entire workshop. Aimed at the characteristics of automobile assembly line, such as multi-level system structure, diversified equipment types, complex and changeable working conditions, and coexistence of a large number of multi-source heterogeneous information, Some scholars [9] realized the efficient visualization management of automobile assembly production by friendly 3D human-computer interaction through the combination of Internet of things technology and computer graphics technology, the in-depth and efficient visualization management of automobile assembly production. The researcher [10] realized the 3D visualization of workshop production process based on unity3d technology and completed the design of workshop real-time monitoring system based on the integration of virtual and real. The scholars [11] analyzed the relationship between digital twin workshop and 3D visualization real-time monitoring. They proposed a multi-level 3D visualization monitoring mode and a real-time data-driven virtual workshop operation mode.

To sum up, some results have been achieved around the three-dimensional visualization monitoring problem of workshop. Such as workshop data acquisition and workshop event modeling have been realized and workshop visual monitoring has changed from two-dimensional to three-dimensional, which can provide more workshop information and improve the transparency of monitoring. However, there are also some problems, such as high threshold of development, low efficiency, poor portability and single monitoring mode, which cannot reflect the status of workshop system. In this paper, a three-dimensional visualization virtual monitoring system of workshop based on industrial Internet of things platform as data application bus is proposed to solve the problems of high threshold, low development efficiency and single monitoring mode. Taking seal workshop as an example, the development process of virtual monitoring system is introduced in detail.

2. ARCHITECTURE OF 3D VIRTUAL MONITORING SYSTEM

This paper combines the powerful data integration and system integration capabilities of the Industrial Internet of things platform and proposes the overall architecture of workshop 3D virtual monitoring system based on the industrial Internet of things platform as the system service platform. As shown in Fig.1, it is composed of physical layer, twin layer, platform layer, application layer and network layer.

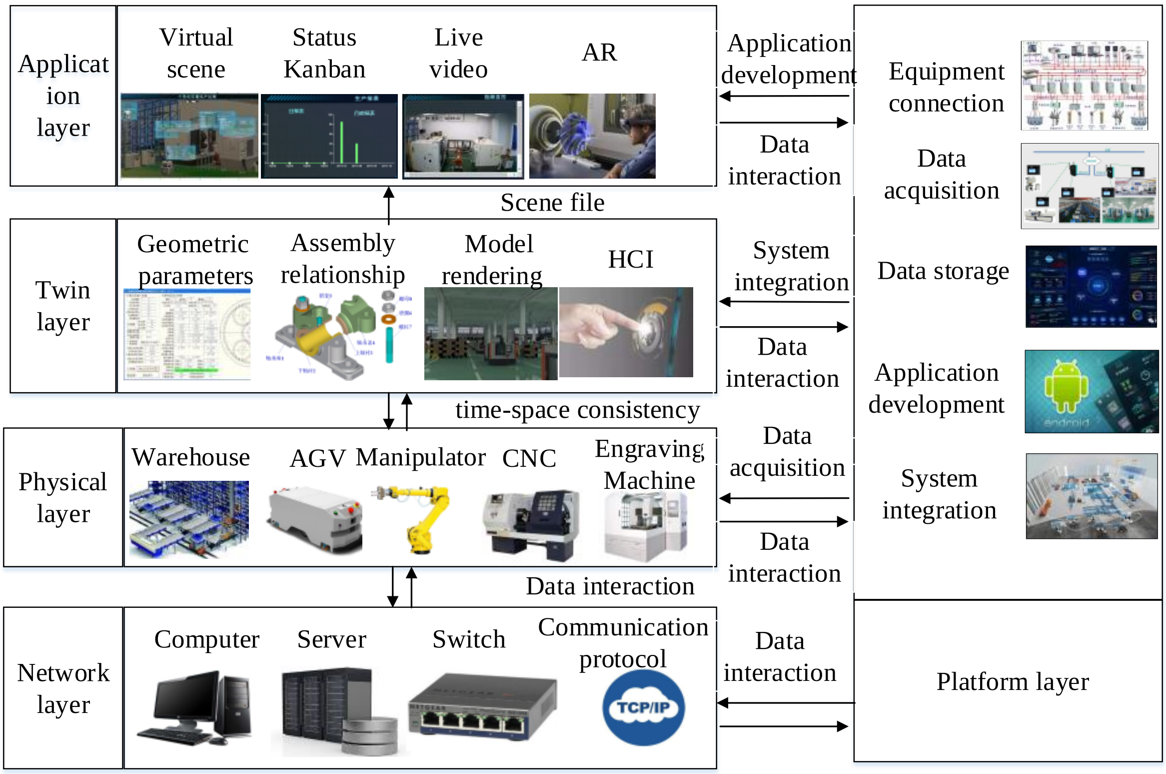

Fig. 1. Overall architecture of workshop 3D virtual monitoring system.

This architecture can meet the requirements of 3D virtual monitoring system of digital workshop for monitoring objects, data acquisition, data interaction, visualization, system compatibility and system portability.

The physical layer is the basis of the three-dimensional virtual monitoring system of the workshop, which is a collection of all elements of the workshop, including equipment, materials, process flow, workshop, etc.; It has typical hierarchical characteristics and according to the function and structure, it can be divided into four levels: equipment level, unit level, production line level and workshop level. Taking the mixed flow automatic production workshop as an example, the equipment in the workshop can be regarded as the equipment level, which is the smallest unit of the workshop; According to the product process, the equipment participating in the same process are regarded as unit level, such as automatic warehouse unit, logistics unit, machining unit, assembly unit, detection unit, packaging unit, etc.

The twin layer constructs the virtual workshop by the way of multi software cooperation and realizes the real mapping of the physical workshop by combining the real-time perception data. The twin layer describes the geometric parameters (shape, size, position, etc.) and the relationship (assembly relationship) of the physical workshop through the three-dimensional modeling technology, so that it has good space-time consistency with the physical workshop. Model rendering technology and virtual reality modeling language are used to further improve the geometric modeling and the virtual workshop has a real texture by adding necessary lights, materials and special effects; At the same time, through the design of human-computer interaction and external input event response, the scene roaming is realized.

Based on the powerful ubiquitous connection, flexible data management and rapid application development capabilities of the Internet of things platform, the platform layer realizes equipment connection, data acquisition, data storage, data service, application development and web front-end system integration.

The application layer, all monitoring contents will be displayed in the application layer. Due to the complexity and unpredictability of the workshop production process, the traditional monitoring methods using data reports, two-dimensional charts and configuration software can no longer meet the monitoring requirements under the current manufacturing mode. As a result, the workshop management personnel cannot obtain accurate information of the production process in the first time, and cannot quickly respond to abnormal production conditions, adjust production plans and guide workshop production. This paper proposes a multi-level workshop display mode, which is mainly based on 3D virtual scene and status Kanban, supplemented by real-time video and augmented reality technology, as shown in Fig. 2. The three-dimensional virtual scene module is used as the main monitoring mode to realize the visual control of the workshop manufacturing process from the three levels of logistics, equipment and products. Although the display effect of status Kanban is not as direct as the three-dimensional model, it plays an irreplaceable role in statistical information attributes (time, text, quantity, etc.), which can display the real-time and statistical information of each production resource in detail. Through a number of industrial cameras arranged on the site, the video monitoring of key nodes in the workshop is realized. Through the integration of video monitoring module, real-time and intuitive monitoring of key links is realized. Augmented reality, AR technology can enhance the real world by comprehensively using three-dimensional modeling, real-time tracking registration, intelligent interaction, sensors and other technical means to overlay virtual information on the real world. Based on AR technology, the visual display of the internal motion state of the equipment is realized.

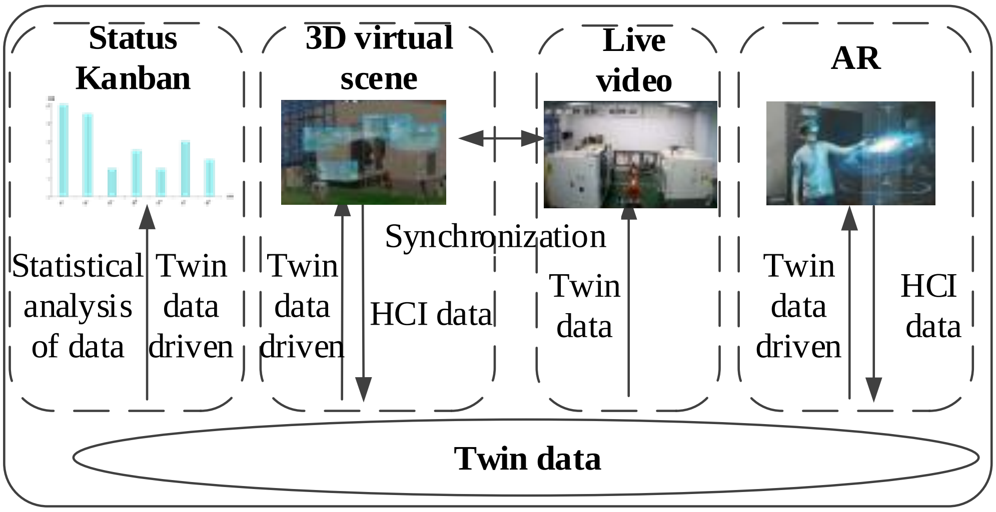

Fig. 2. Display mode.

The network layer is an important link to realize workshop interconnection: It can use a variety of sensors, data acquisition equipment, standard/non-standard communication protocol to collect real-time physical layer data, and transmit it to the platform layer to realize data acquisition, transmission, storage, etc. The two-way communication between twin layer and platform layer is realized through standard software interface, and the model driving based on real-time data is realized. Through interface technology, network communication technology and front-end development technology, data interaction between application layer and platform layer is realized. Platform layer provides interface integration service and data interaction service for application layer, and defines decision rules of human-computer interaction response of application layer.

3. KEY TECHNOLOGIES

3.1 Virtual Scene Construction

As shown in Fig.3, the construction process of workshop virtual scene is mainly composed of geometric modeling, scene construction, human-computer interaction and scene optimization. Geometric modeling is the foundation of virtual scene construction; Scene construction is a further improvement of geometric modeling. By adding necessary lights, materials and special effects, the virtual scene has a real texture; Human-computer interaction includes human-computer interface design, external input event response and so on. It aims to realize scene roaming in 3D virtual scene; In order to balance the contradiction between the complexity of virtual scene rendering and the real-time rendering, and ensure the smoothness of the system in large-scale scenes, it is necessary to optimize the virtual scene and finally obtain the virtual workshop scene model.

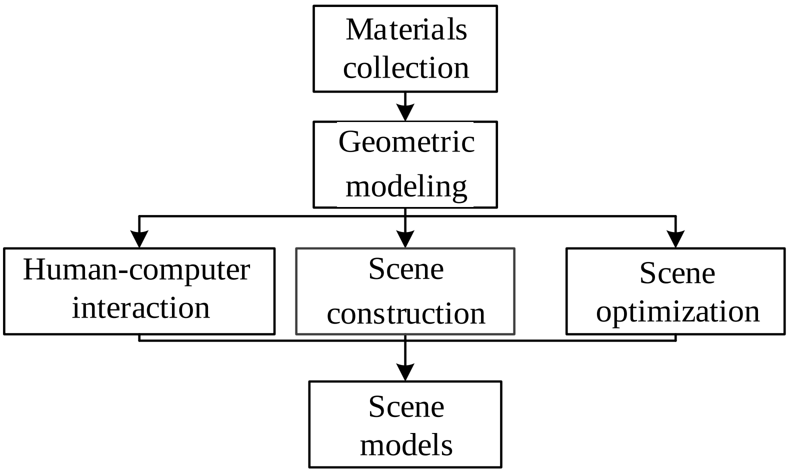

Fig. 3. Workshop virtual scene construction process.

3.2 Data Acquisition Based on the Industrial Internet of Things Platform

3.2.1 Information modeling based on OPC UA

Traditional SCADA, HMI (human machine interface) and other applications communicate with the underlying equipment through the driver. However, due to the large number of automation manufacturers, there is no unified standard for the communication protocol between automation systems, so it is difficult for different manufacturers to integrate software and hardware. OPC UA is a set of standardized technical framework integrating information model definition, service and communication standards. The UA server can be connected with programmable control equipment, CNC machine tools and other field devices through Ethernet to realize the operation of underlying equipment and equipment. After collecting field data and equipment information, the UA server converts them into data supporting OPC UA protocol and provides corresponding service and support for UA client through data management and logical operation. The UA client can be embedded into various programs, device controllers and systems (Internet of things, ERP, etc.) to provide data support services for the upper layer by using the real-time data obtained from the server. The data modeling framework based on OPC UA is shown in Fig. 4.

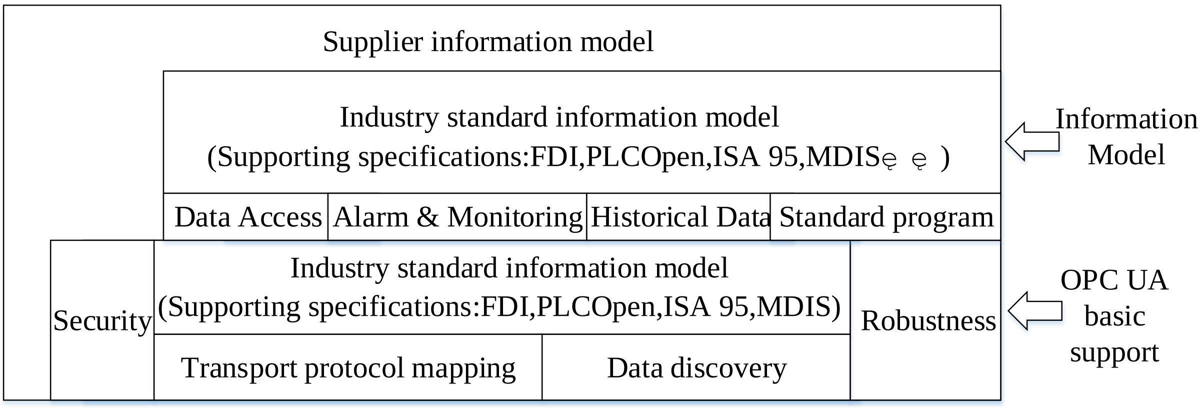

Fig. 4. OPC UA information modeling framework.

3.2.2 Data acquisition process based on industrial Internet of things platform

How to acquire twin data from the massive, heterogeneous and multi-source data flow of the workshop which can represent the real and complete operation state of the physical workshop and realize the interconnection of each layer of the three-dimensional visual monitoring system is the key problem of the system implementation. This paper takes the industrial Internet of things platform as the data bus, with the help of the powerful equipment access, data management and system integration capabilities of the industrial Internet of things platform, reduces the difficulty of data acquisition and management in the workshop, so as to facilitate the rapid development and deployment of the three-dimensional visual monitoring system. The data acquisition process based on the industrial Internet of things platform is shown in Fig. 5, the Industrial Internet of things platform is used as the data bus, high frequency passive RFID is used to collect material information, OPC protocol and equipment software development kit are combined with remote procedure call protocol (RPC) to collect equipment data; Data transmission in JSON format meets the data exchange in different compiling environments; Provide data service for virtual workshop and front-end display based on REST FUL architecture. Firstly, the workshop data acquisition is realized by various data collection methods; Then, the partition selection, storage, catalogue and index of workshop data are realized based on different data management engines such as distributed file system, NoSQL database, relational database and time series database,; Finally, based on the GET method of REST FUL architecture, the data exchange between the upper application and the industrial Internet of things platform is realized.

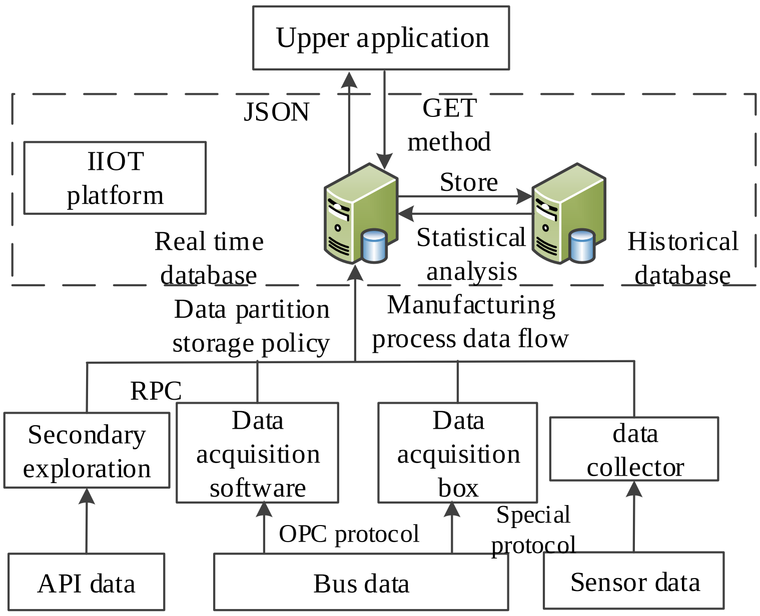

Fig. 5. Data collection process based on the industrial Internet of Things platform.

3.3 Real Time Data Mapping

3.3.1 Data mapping hierarchy

During each state of the workshop operation, the production resources in the workshop will also change dynamically. In order to form a transparent visual real-time monitoring that can cover the whole manufacturing life cycle of the workshop, it is necessary to establish a mapping system at different levels. In this paper, a three-level mapping system of virtual workshop based on real-time data-driven is established from three levels of equipment, logistics and product. On the device level, the virtual mapping of equipment level is the minimum mapping unit of the three-tier mapping system of virtual workshop. The real-time perception of physical equipment action is realized by information sensing technology such as Internet of Things technology, sensor technology, interface technology, and the virtual model is driven by real-time perception data to realize the virtual and real synchronization of physical equipment in the virtual environment. The logistic level mapping drives the flow of workpieces among different workstations by transforming the real-time status data of workshop manufacturing process into corresponding workshop events. The product level mapping is based on the mapping of equipment level and logistics level, convert the process flow, real-time location and real-time status of equipment into workshop events. Based on the event driven method, the dynamic change of product model is realized and the real-time virtual mapping of product state is finally realized.

3.3.2 Data mapping method

The real-time mapping based on twin data is the key to realize the three-dimensional visual monitoring system of workshop. Logistics level: The real-time mapping of material flow process is realized by transforming the real-time data of workshop manufacturing process into event driven; Equipment level: According to the different virtual workshop construction methods lead to different model driving methods. Two model driving methods are introduced in Table 1. Product level: According to the real-time location of materials, product process and equipment status to determine the real-time process of products, so as to realize the real-time mapping of product level.

4. APPLICATION EXAMPLES

4.1 Introduction to Seal Production System

A seal automatic production system is mainly composed of automatic warehouse unit, logistics unit, processing and manufacturing unit, assembly unit and control unit.

Table 1. Model driven methods.

Virtual scene construction methods	Model driven methods description	Typical development software
Based on OpenGL / Direct x underlying API	Based on the underlying API interface. For example, OpenGL provides more than 100 graphics functions, which can be used by developers to build, draw and control the motion of 3D models.	OpenGL with Visual C++, DirectX with visual C++
Multi software collaborative development	Through the integration of the underlying API, virtual reality software defines a series of methods that can be used for model driven.	Unity3D Idea VR

The automatic warehouse is mainly used for storage of materials and finished products; The logistics unit is mainly used for the circulation of logistics, finished products and semi-finished products among various stations; The processing and manufacturing unit is mainly used for product processing; The assembly unit is mainly used for seal assembly; The control unit is composed of on-site general control PLC, CNC system and et al. There are two kinds of processed products: official seal and private seal. The production mode is a typical multi variety and small batch production mode.

4.2 Overall System Architecture

The overall architecture of 3D virtual monitoring system of seal production workshop is shown in Fig. 6, which consists of five parts: physical layer, twin layer, platform layer, application layer and network layer. The physical layer is a collection of all elements of seal production workshop, including personnel, equipment, materials, process flow, workshop, etc. The twin layer constructs virtual workshop in two application environments by the way of multi software cooperation to realize the real mapping of physical workshop. The platform layer realizes the equipment connection, data acquisition, data storage, data service, application development and web front-end system integration based on the powerful ubiquitous connection, flexible data management and rapid application development capabilities of the Internet of things platform. The application layer realizes multi-level monitoring by constructing three-dimensional virtual scene, status Kanban, real-time video and augmented reality. Finally, the network layer realizes the interconnection of all parts of the system through various standard / non-standard protocols and wired / wireless networking.

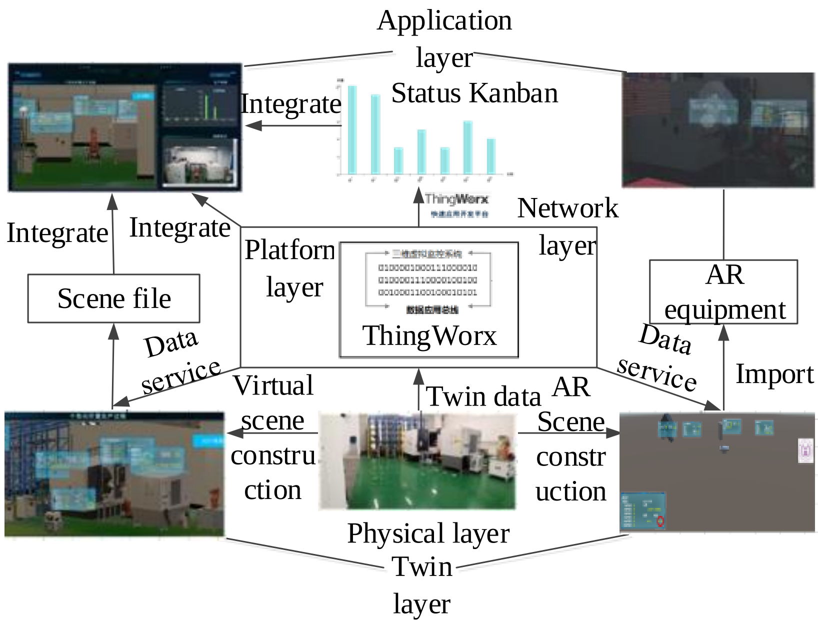

Fig. 6. Overall system architecture.

4.3 System Development Process

The development of workshop 3D virtual monitoring system is a system engineering of multi software collaborative development and multi-functional modules mutual cooperation. In this paper, thingworx Internet of things platform is used as data application bus, and Creo, 3D Max, unity 3D multi software collaborative modeling is used to design and develop a personalized seal production workshop 3D visual monitoring system. The system development process is shown in Fig.7. It mainly includes the following steps.

1. Creo 3D modeling software is used to build the 3D solid model of seal production workshop.
2. Equivalent modeling of workshop entities using 3dmax, rendering the model by giving materials and textures to make the three-dimensional model more realistic. In order to reduce the operating pressure of the hardware, the model is appropriately simplified.
3. Export 3dmax model to .FBX format file. This is followed by importing the FBX model file into the unity3D engine, perform scene management, scene roaming, UI interface design, performance optimization, etc. in unity3D.

4. Collect equipment status information, material information, workpiece information, etc. in the workshop through sensors, IBOX, etc., and send the information to the Thingworx IoT platform for storage using the WebSocket protocol.
5. Divide the data into model driven data and non-model driven data.
6. Non-model driven information is further classified, stored in thingworx in datatable format and displayed in form format.
7. Model driven data unification: It is passed to unity3d engine in JSON string format for visual interactive simulation.
8. Data binding is implemented in unity3d to realize the driving of virtual scene model based on real-time data and the real-time updating of equipment status information.
9. Publish the simulation scene in unity3d as WebGL format and integrate it into thingworx platform.

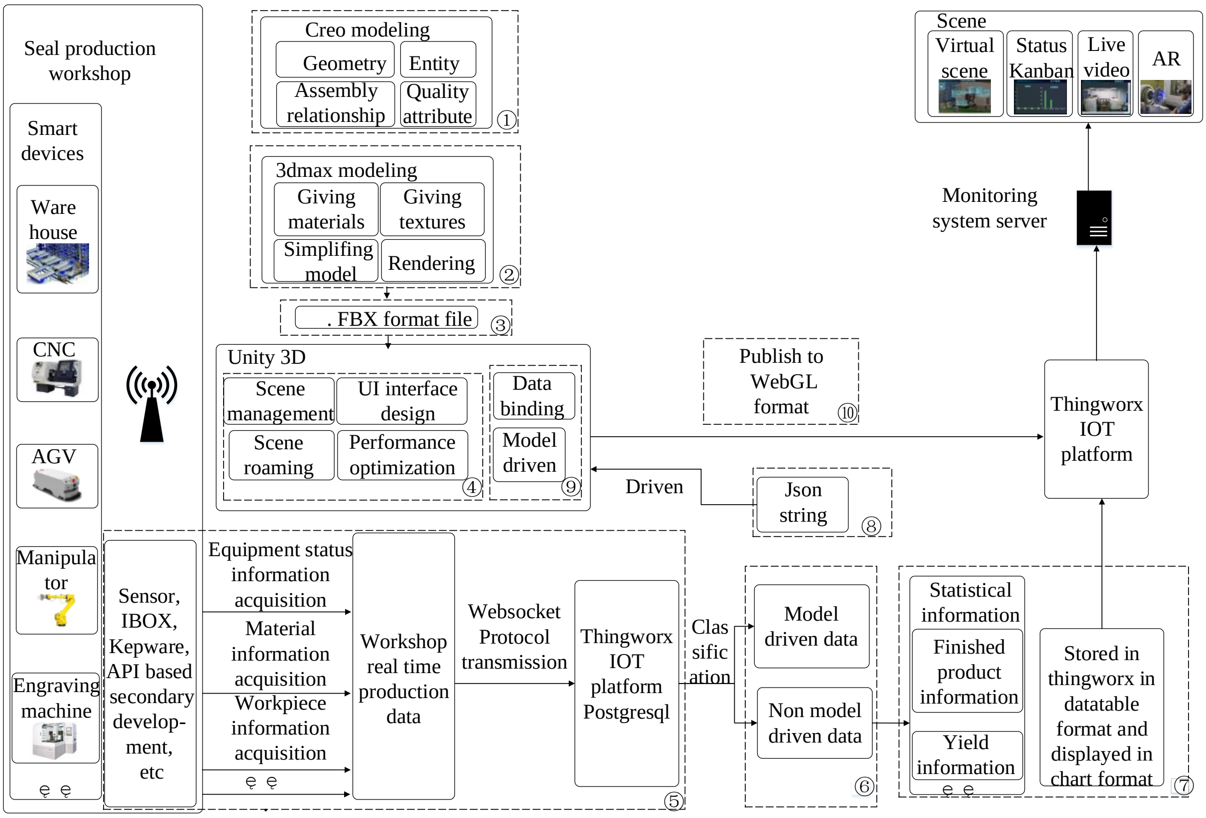

Fig. 7. System development process.

4.4 Virtual Scene Construction

According to the relevant data and on-site mapping provided by the equipment manufacturer, the physical parameters that can represent the seal production workshop are obtained and the geometric models of workshop, equipment, tooling, etc. can be established by using the three-dimensional modeling software Creo. At the same time, the models are simplified, given material, mapped and rendered in 3DMAX.Then the models are exported to. FBX format. Scene management is carried out in unity3d and model position, light, material, etc. are adjusted to make the virtual scene realistic.

4.5 Data Acquisition and Management

4.5.1 Data acquisition

Data acquisition objects include PLC, CNC lathe, precision carving machine, industrial robot, AGV, etc. Taking PLC as an example, the process of data acquisition is explained. PLC data acquisition mainly includes the following contents: location, working status and current task name of stacker and warehousing platform; material information (including processed, unprocessed and to be processed); RFID control information, etc. Siemens S7-1200-1215c is used as the main PLC, so the industrial connectivity module provided by thingworx Internet of things platform can be used to realize PLC data acquisition.

4.5.2 Data storage

Thingworx takes Postgre SQL database as the default standard database, based on the good scalability and compatibility of PostgreSQL database, so as to achieve the system load balance and good data performance balance.

4.5.3 Data extraction

Thingworx has a strong business data integration ability, which can mix data in various business systems to form product life cycle data services that meet the needs of different levels and meet the data requirements of 3D virtual monitoring system in the workshop. This paper uses GET method based on RESTFUL architecture to provide data service for 3D virtual monitoring system of workshop.

4.6 Real Time Data Mapping

The real-time mapping of data is the core of the three-dimensional virtual monitoring system. Based on the static mapping of virtual scene, the real-time data-driven model of workshop field is used to realize the virtual real synchronization of workshop manufacturing process. This paper uses dotween plug-in to realize the real-time mapping of workshop manufacturing state. The device real-time mapping process is as follows: Firstly, the http persistent connection between the virtual monitoring system and thingworx server is established by WebSocket method. After the connection is established, the JSON string in the URL path is called continuously through the GET method; Then the device name is used as index to extract the string related to the device from JSON string and bind the specific data in the string; Finally, by using the DoLocalRotate() method to call the data, the model motion can achieve the effect of virtual real synchronization.

4.7 System Function Realization

4.7.1 Workshop monitoring screen

The virtual scene, status Kanban and real-time video are integrated into the workshop monitoring screen, as shown in Fig. 8.

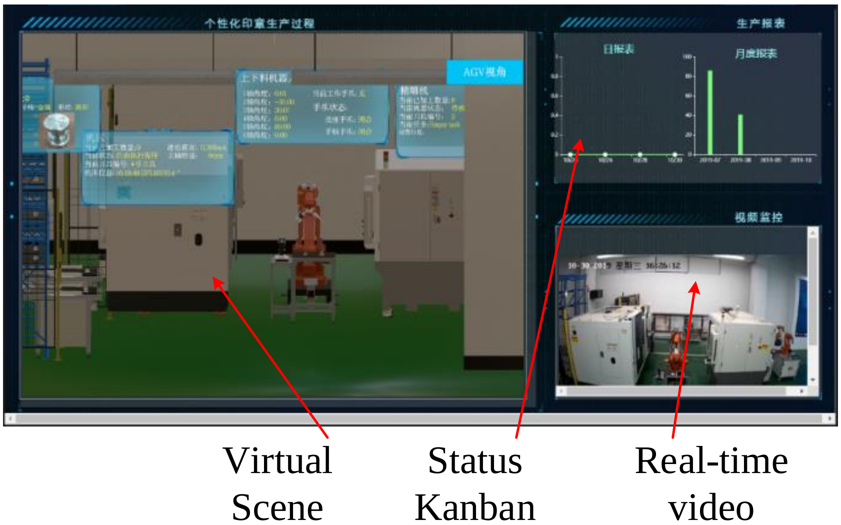

Fig. 8. Large screen for workshop monitoring.

The virtual scene, as the main monitoring mode of virtual monitoring system, has the functions of scene roaming and real-time information viewing of equipment. The 3D virtual monitoring system of seal production workshop realizes scene roaming in two ways: AGV fixed perspective and free perspective. AGV fixed perspective roaming is to take the forward direction of AGV as the first perspective to show every link of the workshop logistics so that managers can observe the whole production process. The effect of AGV fixed perspective observation is shown in Fig. 9. The free perspective refers to that the manager can see the forward, backward, left and right movement of the perspective by clicking the W, S, A, D buttons on the keyboard. The effect of a free perspective is shown in Fig. 10.

Fig. 9. AGV fixed perspective.

Fig. 10. Free perspective.

The real-time monitoring video is used to show the workshop site status of two fixed perspectives. As a supplementary monitoring means of the virtual monitoring system, the real-time video monitoring can show the effectiveness of the virtual monitoring on the one hand, and on the other hand can be used as the basis for fault tracing. The display effect is shown in Fig. 11.

Fig. 11. Real time video monitoring effect.

The status Kanban is based on the bar component of the web frame plug-in provided by thingworx Internet of Things platform. It can quickly create the status Kanban and then through binding the relevant data in the server. It can realize the statistics of workshop capacity and display it on the workshop monitoring screen in the form of histogram, which is convenient for the management personnel to make statistics.

4.7.2 Augmented reality

In the augmented reality scene, the main monitoring objects are the three-axis movements of the CNC lathe spindle, the tool library and engraving machine which are driven by the real-time data. As shown in Fig. 12, part of the operation data are directly displayed in the form of text by using information pop-up windows.

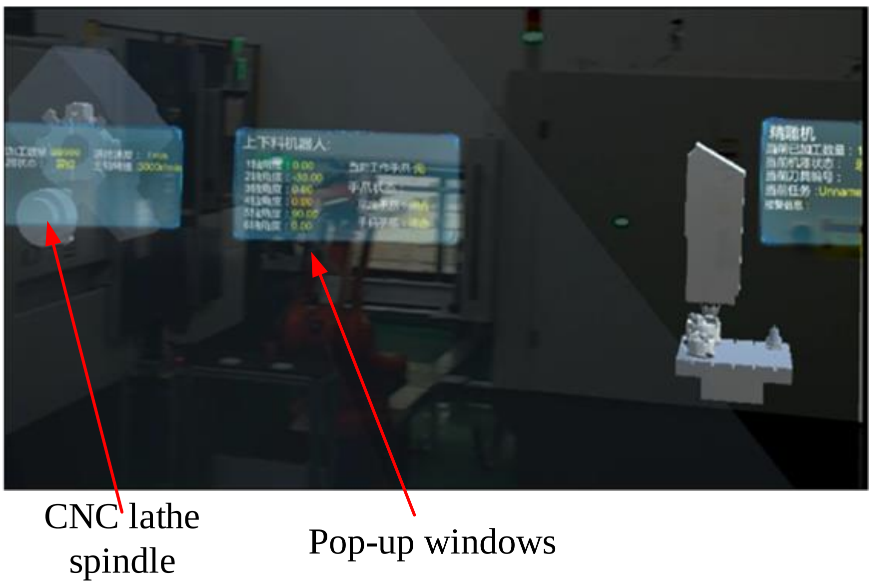

Fig. 12. Augmented reality display effect.

4.7.3 System operation effect

The operation effect of the system is shown in Fig. 13. Through the combination of workshop monitoring screen and augmented reality technology, the production status of the whole workshop is presented in real time. After online, the system runs smoothly and has good real-time performance. After the actual running test, the virtual scene delay is about 0.5s. It can meet the monitoring requirements in the actual production process and achieve the expected design goal of the system.

Fig. 13. Overall operation effect of the system.

5. CONCLUSIONS

In order to solve the lack of effective monitoring methods in the current workshop, this paper studies the workshop 3D virtual monitoring system based on digital twin. The system takes the Industrial Internet of Things platform as the data bus to realize the field equipment access, data acquisition, data management and data service; Through the way of multi software collaborative modeling, 3D virtual scene is built quickly and real-time mapping based on twin data is realized based on Unity3D, so as to realize the visual monitoring of equipment, physics and products; In order to solve the problems of single monitoring form, the system combines AR, desktop VR, real-time monitoring video and two-dimensional data charts to realize multi-level, real-time and visual monitoring of the operation status of the workshop. Taking seal production workshop as an example, the development process of 3D visual virtual monitoring system is introduced in detail. It has certain reference value for the application of virtual monitoring system.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

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