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Article

Design and research of numerical control simulation platform in discrete manufacturing disturbed by vibration

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Abstract: It is of great significance to study the deep integration of manufacturing technology and new-generation information communication technology under vibration interference of machine tools to improve the intelligence level of CNC machine tools. In this paper, a numerical control manufacturing workshop affected by vibration in discrete manufacturing is taken as the research background, and a solution for a digital workshop operation simulation platform based on the industrial internet is proposed. By constructing the simulation environment of the operation process of the digital factory, the generation and transmission of manufacturing information in the digital factory are simulated. The application architecture of the machining workshop based on a numerical control simulation platform is proposed, and the business process of the numerical control machining workshop is analyzed. Then, the key technologies of NC machine tool modeling, synchronous mapping of data and model, data integration, and fusion are studied. Through the integration and implementation of the NC machine tool simulation platform in the machining workshop, the top-down data instructions can be issued accurately, and the bottom-up feedback information can be confirmed in time. Finally, the system is applied to the electronic information and ship machining workshop to verify the effectiveness of the system framework and method proposed in this paper.

Keywords: industrial internet; digital control processing; simulation platform; discrete manufacturing

1. Introduction

Discrete manufacturing enterprises belong to the multi-variety, small-batch discrete flexible production mode [1]. At present, there are some problems in discrete manufacturing workshops, such as the lack of production status immediate control capability, the broken data links of the whole manufacturing process, and the single-point digital island [2]. These restrict the development needs of discrete manufacturing enterprises to realize data-based product quality control, production cycle shortening, and competitiveness enhancement. The digital capability construction of most factories focuses on independent information system construction, which aims to achieve specific functional goals, such as resource allocation, material control, production scheduling, etc. [3]. The one-sidedness, intuitiveness, and availability of information limit the value of data in the manufacturing process.

The future development direction of discrete manufacturing enterprises is to optimize the production control of intelligent factories through high automation, digitalization, visualization, modeling, and integration. Intelligent factory is a new manufacturing and management mode based on the internet platform, which forms an intelligent processing network using equipment monitoring, data transmission, and equipment interconnection, and efficiently completes processing tasks. Industrial Internet [4,5] is a new infrastructure, application mode, and industrial ecology, deeply integrated with the new generation of information and communication technology and industrial economy. Through the comprehensive connection of people, machines, materials, and systems, a brand-new manufacturing and service system covering the whole industrial chain and value chain is constructed. It provides a way to realize the digitalization, networking, and intelligent development of industry, and is an important cornerstone of intelligent factory construction.

With the deep integration of the new generation of information technology (such as artificial intelligence, industrial internet, digital twin) and advanced manufacturing technology, traditional manufacturing is gradually changing in the direction of digitalization and intelligence. Computer numerical control (CNC) machine tools as the manufacturing "industrial machine tool" [6,7], their intelligence degree has an important impact on the implementation of intelligent manufacturing in discrete industries.

It is of great significance to study the deep integration of machine tool vibration condition monitoring [8] and network communication technology, sensing technology, and information processing technology to improve the intelligent level of CNC machine tools. At present, monitoring methods of NC machine tool operation in discrete manufacturing workshops are mainly two-dimensional charts, which are single in form, lacking virtual model and simulation analysis ability, and have poor interaction ability between virtual and reality [9,10]. In addition, because the monitoring is mostly located at the site station, the abnormal perception and processing are not timely [11], which easily causes product quality defects or machine failures.

Industrial internet and digital twin, as carriers to promote the integration of new generation information technology and the manufacturing industry, have become the core key technologies of intelligent manufacturing. It has broad application prospects in the aspects of healthy management and predictive maintenance of equipment [12,13], intelligent production lines [14], intelligent workshop management, and operation and optimization [2]. The development of industrial internet technology has realized the interconnection of everything at the workshop level, collaborative manufacturing at the supply chain level, and cloud manufacturing access at the social level. Industrial internet extends the value chain and life cycle of digital twins, highlighting the advantages and capabilities of digital twins based on models, data, and services. The industrial internet has opened up the realistic path of digital twin application and iterative optimization. The digital twin is the key technology and an important scene of the industrial internet.

As an effective method to realize the real-time interaction and integration [15] between the physical world and the information world, digital twin [16,17] technology controls the physical workshop equipment with the help of relevant data and algorithm models [18]. In the offline simulation mode [19], the digital twin machine tool runs the simulation independently according to the parameter settings, which are used for the verification of instructions before the actual machining and NC program. In the synchronous online simulation mode [20], the state and operation data of the physical machine tool are updated to its virtual model in real-time through the twin mapping mechanism. The visual monitoring of the NC machine tool is realized. Remote control [21] means that the twin machine tool sends instructions to physical equipment through synchronous simulation and data analysis, and controls the machine tool reversely for exception handling. Digital twin machine tools [22] obtains relevant information through Ethernet and other communication hardware, stores or reads data rely on the database, sends instructions to the numerical control subsystem through the data model, and controls the physical machine tool in reverse. The algorithm library provides algorithm analysis support for the data model, and further combines offline simulation, synchronous simulation and remote control in the service model to form a complete digital twin machine tool status monitoring mechanism [23,24]. The 3D visual monitoring based on digital twins can accurately and truly simulate the actual situation of the machine tool processing site.

During the production process, data are collected and mapped to the digital twin model in real-time. This will reflect the running state of the machine tool more intuitively and effectively. Through remote control, the abnormal state can be handled in time, and the failure rate can be reduced. Therefore, it is of great significance to research CNC simulation platforms in discrete manufacturing processes.

In this paper, a numerical control manufacturing workshop of a discrete manufacturing industry is taken as the research background, and a solution of a digital workshop operation simulation platform based on the industrial internet is proposed. The installation and deployment of hardware equipment, networking communication, and software development are completed. The simulation environment of the digital factory operation process is constructed to simulate the generation and transmission of manufacturing information in a digital factory. The functions of industrial information collection and display are realized.

2. Application architecture of the workshop based on the numerical control simulation platform

The numerical control simulation platform of digital factories opens up the integrated communication between the software system and hardware equipment by constructing hardware equipment, software systems, and industrial networks. The application architecture of the digital CNC workshop is shown in **Figure 1**. The platform covers product design, process simulation, numerical control programming, equipment operation simulation, workshop production operation simulation, production management, equipment status monitoring, and other business links. The scenario of virtual and real integration of a digital twin-based factory operation is constructed. By establishing the simulation platform of digital equipment networking in the workshop, the industrial transmission network of digital equipment networking and communication is built. The networking of digital equipment in the workshop, data acquisition, program transmission, and real-time monitoring of equipment status are realized. By establishing simulation information points such as Ethernet and Fieldbus, the simulation of industrial Ethernet and Fieldbus is realized. A simulation operation environment for centralized monitoring and decentralized control of basic operations such as production planning, technical preparation, and processing operation of the workshop is established in the simulation platform.

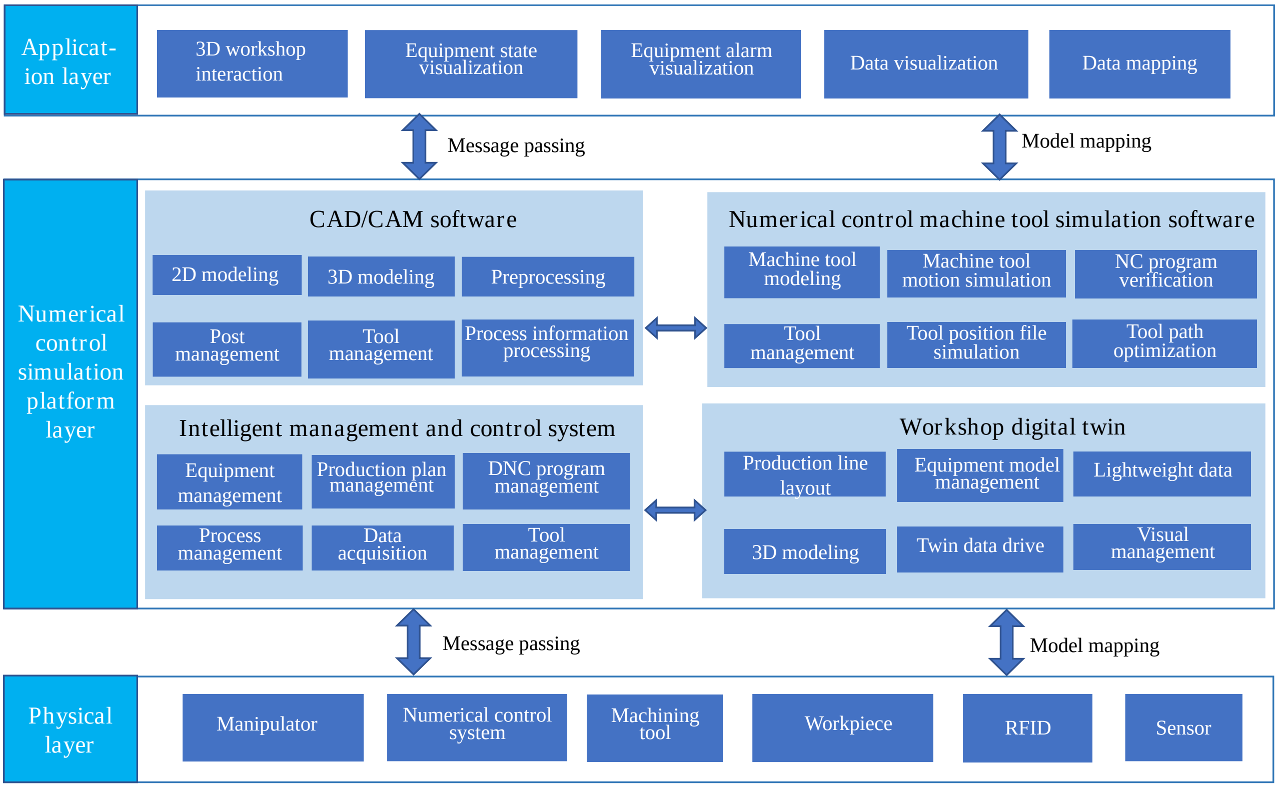

Figure 1. Application architecture of digital CNC workshop.

Three-dimensional models of CNC equipment and additive equipment on the workshop production line are displayed. Combined with the data collected at the bottom, the workshop process is driven and simulated. The function of virtual-real combination is realized. This will more intuitively reflect the overall operation state of the workshop. According to the real space, the workshop model is established. The corresponding changes are made in combination with the operation of the production line. The real-time data of the equipment can be displayed on the model. This can intuitively reflect the running state of the equipment and facilitate the management of the entire workshop.

Virtual workshop is driven by the new generation of information technology and manufacturing technology, through the real mapping and real-time interaction between physical workshops and virtual workshops. The integration and fusion of all elements, processes, and business data of physical workshops, virtual workshops, and workshop service systems are realized. Driven by the twin data of the workshop, the iterative operation of workshop production factor management, production activity planning, and production process control among the physical workshop, virtual workshop, and workshop service system is realized. Therefore, under the premise of meeting specific objectives and constraints, a new workshop operation mode with optimal workshop production management and control can be achieved. The physical factory mainly consists of equipment used for production and manufacturing on the shop floor, including CNC machine tools, CNC systems, additive manufacturing equipment, etc., simulating actual manufacturing scenarios. The workshop system integration and data flow diagram are shown in **Figure 2**.

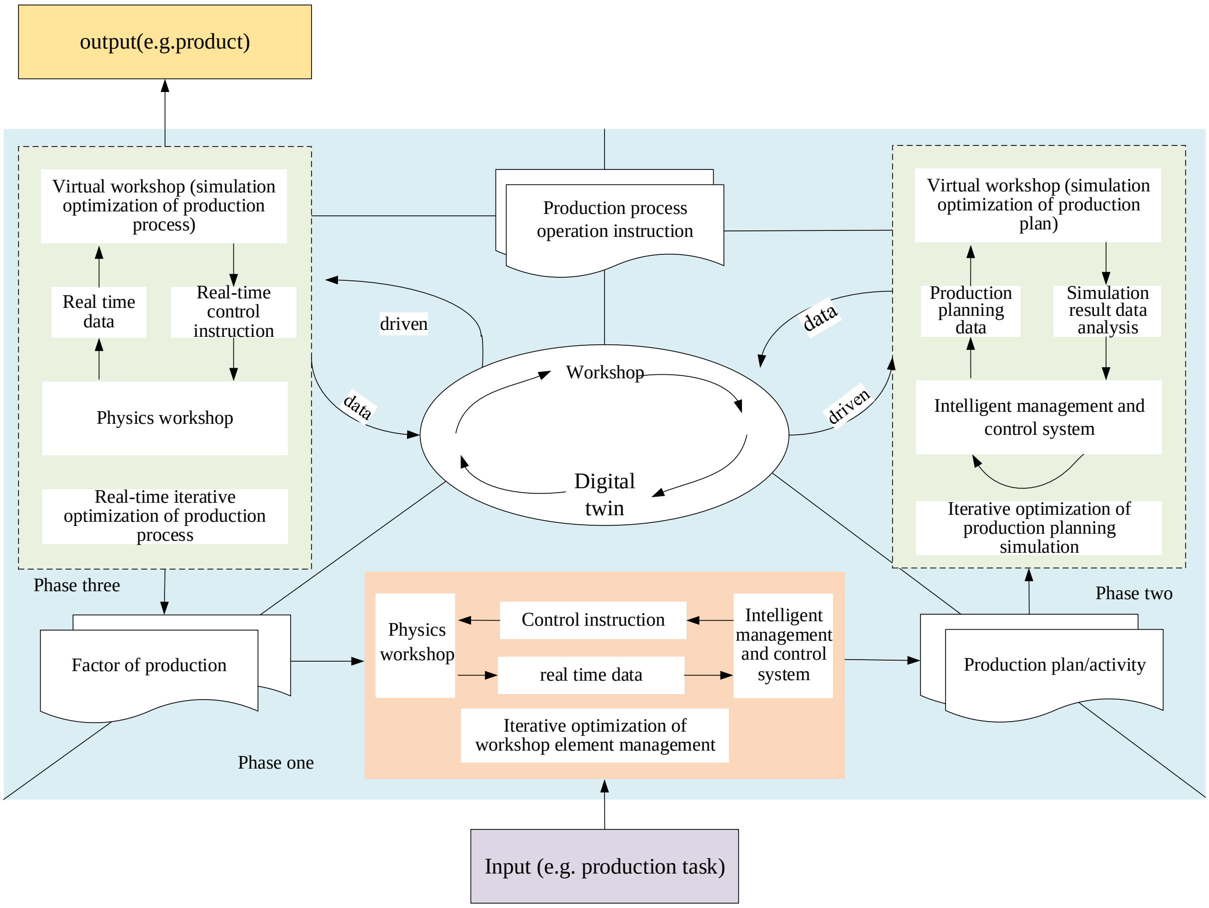

Figure 2. Workshop system integration and data flow diagram.

3. System architecture of CNC simulation platform

The CNC simulation platform system is based on the B/S (browser/server) architecture, which can be accessed through the browser, as shown in **Figure 3**. The system adopts the J2EE architecture, which has strong scalability and supports dual-machine hot backup or distributed deployment to ensure stable and reliable operation of the system. The system has a variety of interfaces, which can transmit data from the CNC simulation platform system to other IT systems and can also automatically read third-party system data. The CNC machine tool modeling adopts a lightweight model to avoid the requirements for the performance of the workstation. The server mainly completes the system platform construction, real-time data acquisition, and data-driven model. The client receives the real-time data pushed by the server and completes the lightweight 3D model displayed on the web page is no need to install additional client software. The software composition of the CNC simulation platform system is as follows:

The visual display is presented through the web page, and the model can be operated in three dimensions, viewed, and roamed automatically. Data collection and visual display of equipment basic process can be provided. The visual display supports the real-time dynamic display of different data sources through scalable vector graphics (SVG). Based on large-scale production data, key data are archived, counted, and analyzed. Statistical analysis reports are automatically generated through web-based reports. The real-time motion of digital models is driven by real-time data, which realizes the common motion of digital models and real equipment. A data acquisition gateway supporting various types of controllers (including robots, processing equipment NC, PLC) realizes real-time data acquisition and transmission of the target object. By dynamically driving parameterized configuration, the data source of the data acquisition gateway and 3D model editing are parameterized by the system. The realization of code-free configuration in the editor can realize the model parameter-driven work.

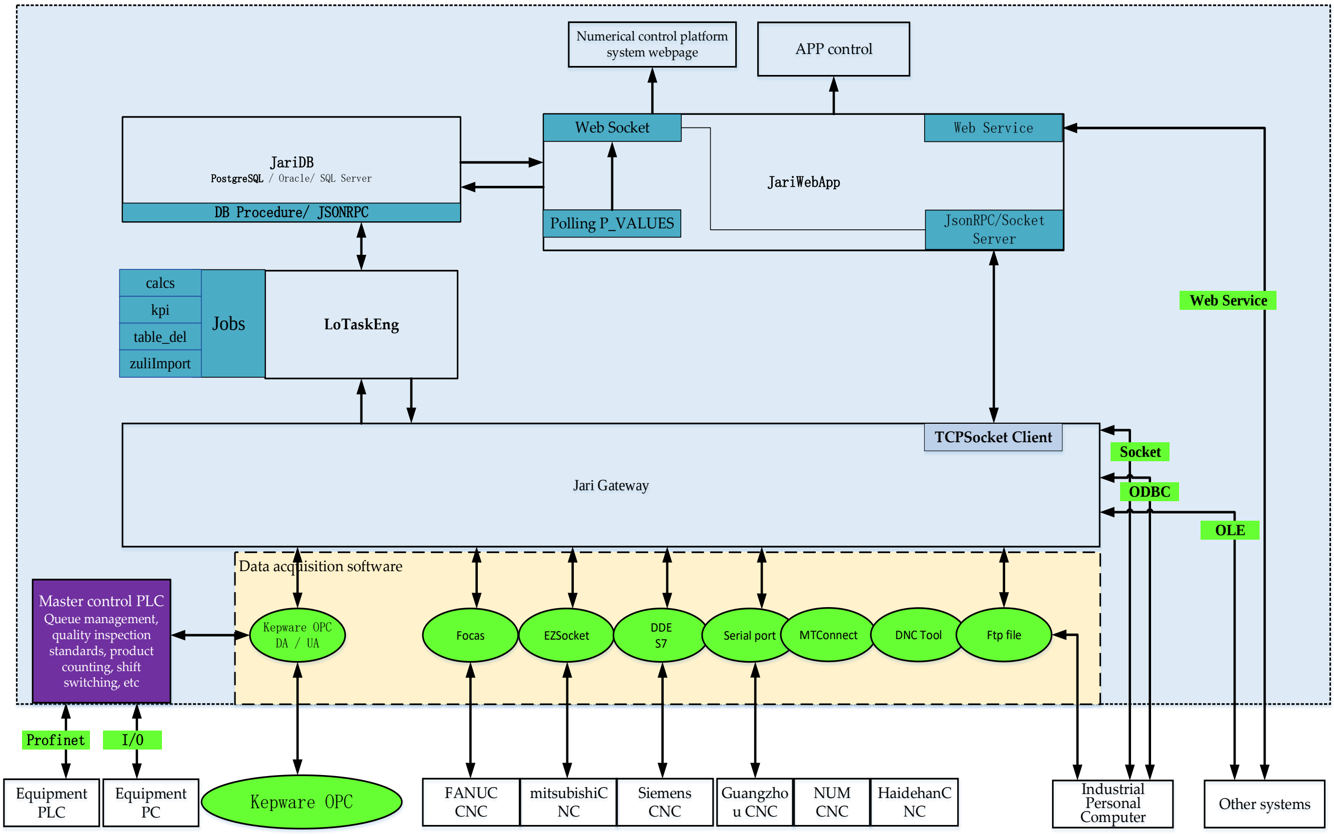

Figure 3. The system architecture of the CNC simulation platform.

4. Key technology research

4.1. CNC machine tool modeling

Because the actual workshop structure is complicated. In the process of modeling, systematic planning, and design should be carried out first. The workshop is divided into several modules, such as individual workshop equipment, workshop production line coordination, etc. The specific relationships between models are determined, such as the constraint relationship, the "parent-subclass" relationship, and the parallel relationship, etc. Then, digital models are built in the three-dimensional platform according to the divided modules, and corresponding effects are added to the models according to the actual state of the workshop. Finally, according to the relationship between the divided models, the overall model of the workshop is integrated and assembled. Heydarnia et al. [25] studied the vibration behavior of the feed drive system by modeling the CNC cutting machine tool to improve the performance of the machine tool in the manufacturing process.

Due to the large number of models in discrete manufacturing workshop scenes, the number of models automatically generated by industrial modeling software is large. Therefore, the most important factor affecting the running smoothness of this system comes from the model. If the model obtained from lightweight software is used directly, the smoothness of the system will be unsatisfactory. Therefore, it is necessary to simplify the model. The main purpose of simplification is to reduce the number of models and unnecessary components of the model to improve the smoothness of system operation. The main parameter that determines the picture quality or running fluency is frames per second (FPS). It means the number of frames transmitted per second, and the larger the value, the smoother the running picture. According to the workshop layout in the real factory, the processed model is placed in equal proportion according to the actual location and space size of the workshop. The equipment modeling is used between workstations to divide the various areas of the workshop. Finally, the production line and equipment layout of the workshop are completed.

The virtual three-dimensional models of the machine tool workshop on-site environment, CNC machine tools, and tools are constructed in this paper. The CNC simulation platform can drive the operation of digital twin virtual equipment based on the operation data of the production site. By establishing a three-dimensional digital model of the CNC machine tool production line, the physical equipment is mapped to the virtual model equipment. The synchronous movement of the digital CNC machine tool equipment is driven in real-time. The digital machine tool includes a 3D geometric model, a physical model, and a kinematic model. Geometry models are used to express the visual effects of mechanical component mapping in the information space, with consistent shape size and motion relationships, and geometric models use lightweight triangulation data to describe the shape and size of the equipment. The geometric transformation of the model and the lightweight display function of the model in the browser are realized by the secondary development technology of Revit and the technology of the web graphics library. The physical models specify the mechanical and thermodynamic states of the CNC machine tool equipment in the parametric data. The physical model of the hinge or rigid body is added to the model base by visual and parametric components. The kinematics models specify the motion pair of the device and are used to describe the connections between the components of the device.

The scope of information modeling of the CNC machining workshop includes information points of equipment, instruments, production, and production auxiliary systems. The geometry of these modeled objects should be consistent with the appearance, size, and location of the physical production line. Each modeling object is bound with a unique identification code. The operation data of the production equipment model is mainly collected from the production management and control system. Through the data interface model, the integration of the CNC simulation platform system with the production management and control system and equipment acquisition system is completed. Data mapping from real scene to virtual space is established through a data acquisition gateway. Combined with the control script of the virtual model, it is transformed into virtual and real behavior mapping, state mapping, and alarm information mapping. Process information modeling refers to the definition and modeling of the number, role, preconditions, main event flow, abnormal and branch event flow, and post-conditions of the production line process. The simulation information data is collected from the production management and control system. It is abstracted and simplified as the input of the numerical control simulation process. The simulation information model needs to be able to use the virtual digital twin model to simulate the efficiency of physical actual production equipment according to the historical accumulated production data and equipment operation data, to realize the mutual mapping between virtual and reality.

4.2. Data and model synchronization mapping

The mapping between physical entity and virtual space is divided into real-to-virtual mapping in which manufacturing workshop data is sensed and transmitted to digital space. The other is the mapping of decision-making and optimization instructions sent back from digital space to physical space. Twin model can keep interaction and symbiosis with the state and performance changes of intelligent machine tools, and then improve the performance of intelligent machine tools. Zhang et al. [26] studied the network physical machine tool based on edge computing technology to reduce the mapping delay. Sun et al. [27] verified the synchronous mapping between the twin model and the physical machine tool by changing the training data set. The prediction of the feed rate and processing cycle is realized. Heo et al. [28] optimized NC code by synchronously mapping machine tool spindle load and NC data. Li et al. [29] studied the data-driven machine tool condition monitoring, including the prediction and control of machining surface integrity and cutting vibration. Liu et al. [30] established a digital twin model driven by data in the machining process. It is used to study surface roughness prediction and process parameter optimization. Cao et al. [31] combined industrial internet and digital twin technology to build a numerical control simulation system, which realized real-time simulation of the geometry, cutting force, and tool wear of CNC machine tools. The system is tested and verified in commercial airline workshops. The results show that the proposed digital twin system of cloud-edge cooperation can realize synchronous command and machining simulation trajectory. Guo et al. [32] realized the online prediction function of tool wear by constructing the twin model of CNC machine tools. The experimental verification was carried out in the manufacturing process of marine diesel engine cylinder liner. The results show that the developed system can effectively monitor machine tool data and avoid tool collision during machine tool processing. Qi et al. [33] studied the surface machining monitoring system based on digital twins and conducted experimental verification in the machining process of large complex curved surface workpieces in aerospace. The results show that the system improves the visualization effect of virtual-real mapping in the simulation process. Williams et al. [34] proposed a digital twin CNC machine tool to simulate the whole coin manufacturing process to verify the correctness of the proposed method. The results show that the digital twin system can replace the real system to analyze the spindle speed and position of the machine tool. Therefore, it is of great significance to study the synchronous mapping of data and models of CNC machine tools to improve the production efficiency of enterprises.

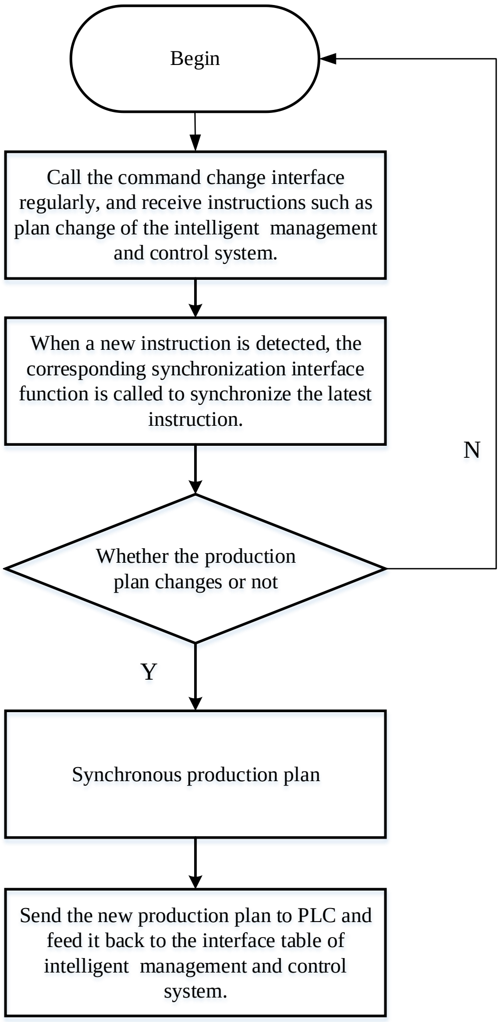

Figure 4. Flow chart of driving equipment model of CNC simulation platform system.

The numerical control simulation platform system can be integrated with the data acquisition gateway of intelligent management and control systems. It can also be connected with an external equipment data acquisition (MDC) system to obtain the real-time operation data of the equipment. Real-time data collection and transmission of target objects are realized. The equipment data acquisition period is not more than 500ms. Data acquisition middleware can connect a variety of types and brands of machine tools, and equipment, including CNC systems, programmable logic controller (PLC) controllers, industrial computers, databases, etc. The CNC simulation platform system collects the data of physical workshop equipment, production lines, and terminal controllers in real-time, including equipment operation status, alarms, production data, drive data, running data, and other equipment-specific equipment production and status data. The CNC simulation platform system can drive the operation of the digital twin virtual equipment based on the operation data of the production site, as shown in **Figure 4**.

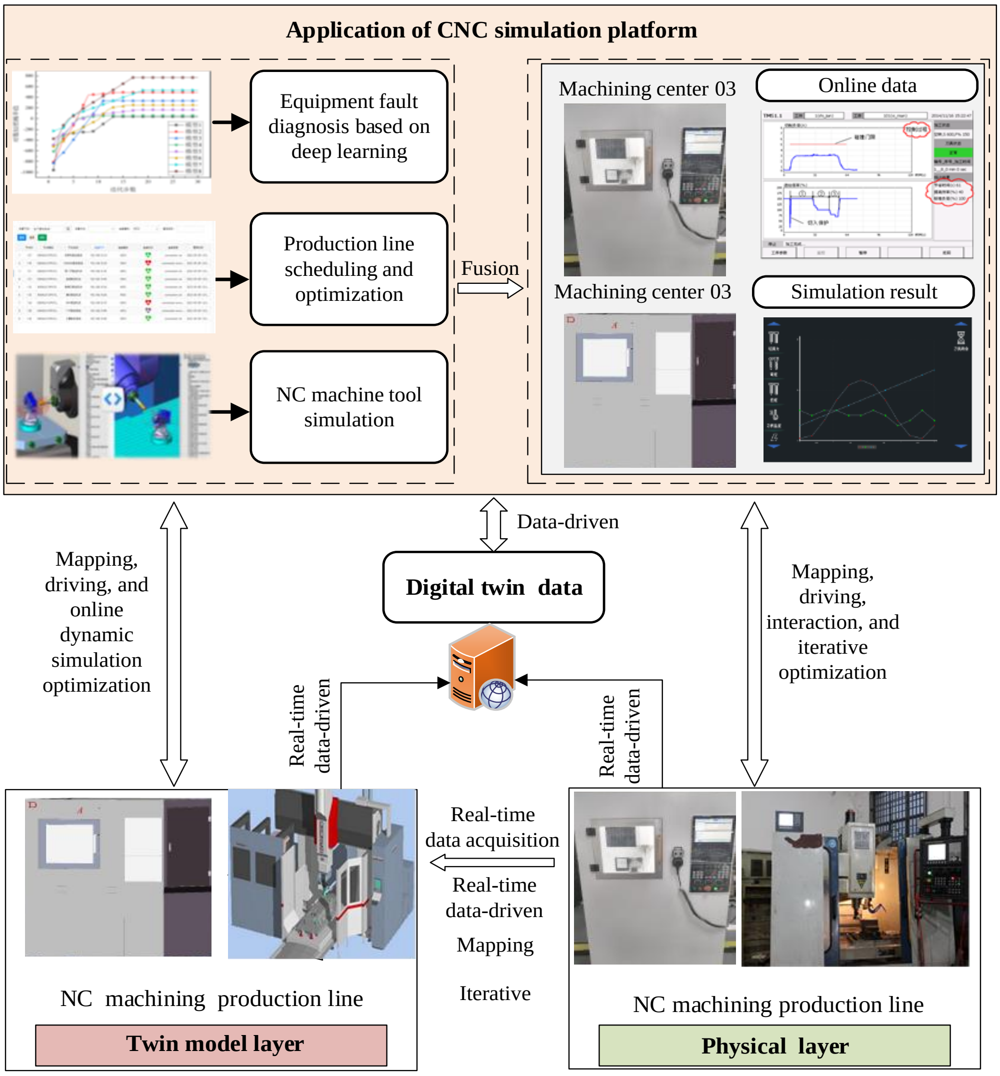

Figure 5. Mapping mechanism diagram of CNC simulation platform.

The physical entity, twin model, mapping mechanism, and information flow of NC machine tools in the NC simulation platform developed in this paper are shown in **Figure 5**. It mainly includes NC machining equipment in the physical layer, virtual machining equipment in the twin model layer, a twin database of virtual and reality interaction, and an NC simulation application platform. During the virtual-reality interactive mapping, real-time data, algorithms, and models are called through twin databases. Finally, the mapping result is dispatched to the interface database. When the entity state of the object is updated, the data obtained from the data acquisition gateway is sent to the twin model. On the contrary, when the virtual scene status is updated, the monitoring data is extracted from the data buffer and sent to the corresponding equipment in the workshop.

All twin equipment models can be updated and optimized in real-time according to manufacturing requirements. The interaction between twin models is realized by digital threads. After the CNC simulation platform is running, the virtual and real state matching is carried out according to the real-time data collected by the data acquisition gateway. The platform sends a motion drive request instruction to call the motion drive algorithm. The CNC simulation platform sends the received kinematic model data to the corresponding equipment. The position of the corresponding components in the equipment is updated through the motion pairs such as the spindle. Finally, the geometric model of each NC machine tool is updated in the three-dimensional scene to realize the synchronous mapping of data and status between the twin model and the physical machine tool.

The simulation platform can simulate the production process and predict the order completion time by collecting the production time and calculating the production load. A virtual manufacturing simulation system carries out virtual manufacturing before actual production. The simulation analysis results are transmitted to the production planning system. The simulation results of the production planning information, process information, and execution strategy are transmitted to intelligent management and control systems. The intelligent management and control system receives the production plan and process information from the numerical control simulation platform and transmits it to the equipment layer through the field control PLC.

The CNC simulation platform system regularly calls the JsonRPC interface function command_change to synchronize the latest changes. Automatically synchronize production plans according to the types of changes, such as planning, technology, and quality. The updated production plan is distributed to the corresponding equipment. According to the signal triggered by the equipment task list, the corresponding interface function is called. According to the result of command_change, the change of process standard or quality standard is automatically updated. The latest data are sent to the corresponding equipment. According to the trigger signal of the state change of the task list, the data of the task list, such as the over-point information, processing results, and quality inspection results, are automatically updated. Finally, the basic data of product traceability is formed.

4.3. Data integration and fusion

Through data soft acquisition and hard acquisition, the data acquisition of multi-source heterogeneous equipment on site is realized. It is compatible with a variety of equipment industry protocols, and effectively collects data from a variety of equipment and uploads it to the database through the network. Through the CNC simulation platform, the running status of the manufacturing equipment is monitored in an all-around way, and the equipment abnormality is quickly responded to. According to the different types of equipment, the control mode of the equipment is divided into several communication modes such as serial port, network port, or network port with a network card, etc. CNC machine tools have an Ethernet port as a data acquisition interface, and data can be directly acquired through soft acquisition.

For PLC with only a serial port, this part of data collection adopts the method of installing a serial port server. The serial port protocol is converted into Ethernet protocol for data upload. For the network port with self-defined protocol, according to the different PLC protocols, the corresponding protocol can be directly developed for data soft acquisition.

Some devices that can't directly perform soft acquisition choose to install a protocol converter to convert the protocol before data acquisition. The collected data is uploaded to the management system or interacted with other systems in the form of a network port. The forms of data acquisition can provide comprehensive data acquisition by adding a data acquisition gateway, digital/analog acquisition gateway, and soft acquisition (open software interface API, etc.).

In order to realize the deep integration of physical workshops and virtual workshops, the mapping relationship between them can be realized by the data-driven method of physical workshops. Specifically, it is through the collection of state data of the physical workshop, such as the collection of equipment state data. By taking the data as the parameters of the workshop model, the parameters of the virtual workshop model are constantly updated. The synchronization between the virtual workshop and the physical workshop can be realized. Based on this demand, the data-driven function of the virtual workshop can be realized by script programming on the basis of data collection, so as to achieve integration with the physical workshop.

Data acquisition is realized for multi-source heterogeneous devices, and the collected data is edge calculated and preprocessed. And the data is saved to the database for application layer software to call. For physical objects (such as people, things, events, etc.), the accuracy, extensiveness and depth characteristics of internal relational data are integrated. Through the intelligent association of all kinds of data sample attributes and resources, the multi-source data fusion in the data layer, feature layer, and mode layer is handled from multi-dimensional, multi-modal, and time scale and space dimension. Through pattern recognition and machine learning algorithms, a consistent explanation or tagged description of the observed object or state is obtained. The pull-through identification of entity ID is realized. The multi-source information fusion is completed.

Through the WS adapter, the API interface for obtaining the equipment data of the NC simulation platform is provided. Finally, the requirements of displaying the data of NC equipment in an integrated system is realized. The system is integrated with the data acquisition system of the equipment operating a state monitoring system. The adapter integration is shown in **Figure 6** and the workflow is as follows:

The service requester sends a request message to the Webservice, which is converted into a data provider request message after logical processing. The data provider obtains the request from the provisioning queue. After the data provider parses the request message and processes it, the processing result is combined. The response is sent to the response queue, and the requester obtains the response from the response queue. The data interface can provide monitoring and abnormal alarm (message reminder mechanism), and generate a log. The log file supports the query according to retrieval conditions.

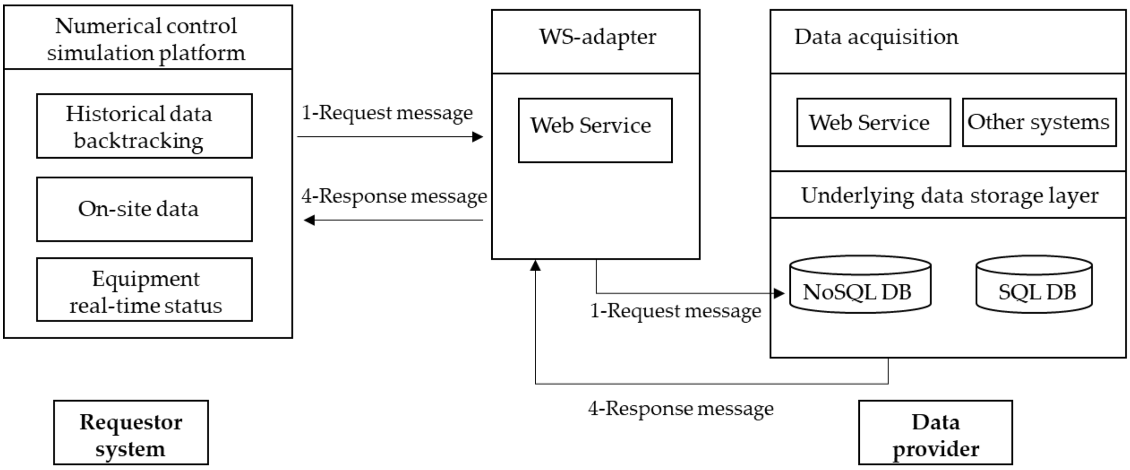

Figure 6. The integration of adapter.

5. Implementation effect

The numerical control simulation of the processing workshop of an electronic information enterprise is taken as the application research object. The numerical control system adopts the Siemens five-axis linkage controller, NUM five-axis linkage controller, Heidenham five-axis linkage controller, and Huazhong numerical control five-axis linkage controller respectively. The OPC UA is adopted for Fieldbus communication. The functions in the library are called by high-level programming languages C++ and C# to set and extract the internal parameters of the CNC system. The control and data acquisition of CNC machine tools are completed. From the operation mechanism and data flow diagram of the physical workshop and twin workshop in **Figure 2**, it can be seen that the NC simulation platform can monitor and optimize the production process in real-time. It can also optimize the production plan. The CNC simulation effect diagram of the machining production line of an electronic information enterprise is shown in **Figure 7**. The simulation operation flow of the parts machining process is as follows:

According to the actual needs of production, the twin model modeled in the previous “CNC machine tool modeling” can be selected, and the uncomplicated CAD format information can be directly imported, or the general lightweight models such as step, x_t, and igs can be imported. According to the actual programming situation, the tool library is created in the software, and the detailed information of each tool is set. According to the actual information, information such as machining origin, compensation, initial position, and initial variables are set. The actual machining code is loaded for full program verification, interactive tool path simulation, automatic error detection, and accurate machining cycle prediction. Then the whole machining process of the parts (such as spindle stop, part cutting, etc.) is simulated. Comparing the simulation results with the design model, the material overcutting or material residue can be quickly checked according to the tolerance requirements.

The main data sources in the workshop are composed of equipment and workstation data, material middleware data, team data, and production task data. The above data information is collected by means of sensors and monitoring instruments, and the original data is generated. The collected data are transmitted to the MySQL database by HTTP protocol. The corresponding data in MySQL is obtained by scripts in the client of the CNC simulation platform, and displayed in the form of reports and work orders.

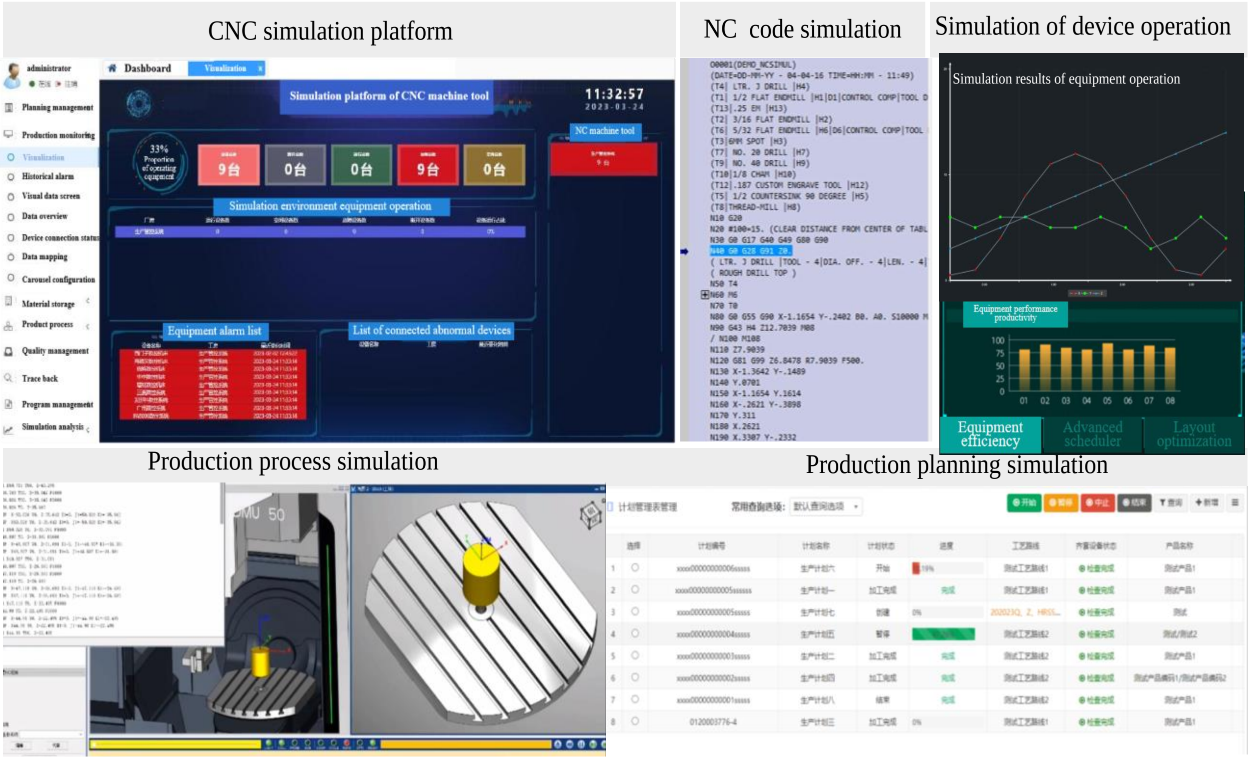

Figure 7. Simulation effect diagram of CNC simulation platform.

The data mapping between the machine tool motion mechanism and real equipment in the twin mapping model is constructed. The data mapping includes function mapping, communication interface mapping, action behavior mapping, and operation rule constraint mapping of CNC machine tools. Then the digital twin mapping model is driven to complete the functional response to different signals. The virtual device and the real device can realize synchronous movement. After the CNC simulation platform is running, the virtual and real state matching is carried out according to the real-time data collected by the data acquisition gateway. The platform sends a motion drive request instruction to call the motion drive algorithm. The CNC simulation platform directly displays the received physical model data and records the data in the twin database for further optimization of the algorithm. The CNC simulation platform sends the received kinematic model data to the corresponding equipment. The position of the corresponding components in the equipment is updated through the motion pairs such as the spindle. Finally, the geometric model of each NC machine tool is updated in the three-dimensional scene to realize the synchronous mapping of data and status between the twin model and the physical machine tool. The virtual-reality interactive diagram of abnormal monitoring in the electronic machining workshop is shown in **Figure 8**.

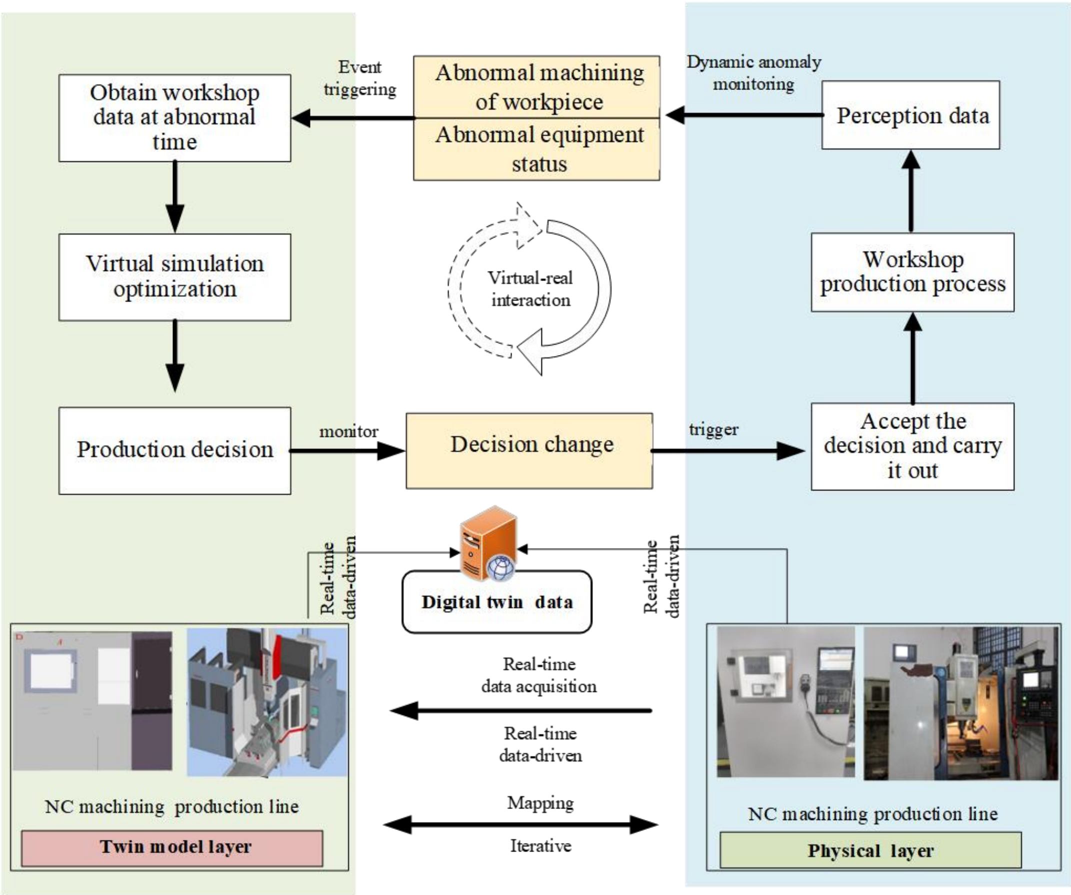

Figure 8. Workshop abnormal monitoring virtual-reality interaction diagram.

The CNC simulation platform is used to simulate and verify the whole production process of NC machine tools. By copying physical CNC machine tools in digital space, machine tool simulation, ontology simulation, and code simulation can be realized in advance. The simulation platform of the NC machine tool adopts B/S architecture. Its system response time is less than or equal to 500ms. The acquisition time of equipment status parameters and order information data does not exceed 500 milliseconds. The obtained real-time picture refresh frequency of production line equipment and sensors is not less than 30 Fps. The simulation platform can display the position of machine tools according to the layout of workshop equipment. It can also display equipment status information in real-time. The NC simulation platform supports viewing the real-time status information of each device at the monitoring client, as shown in **Figure 9**.

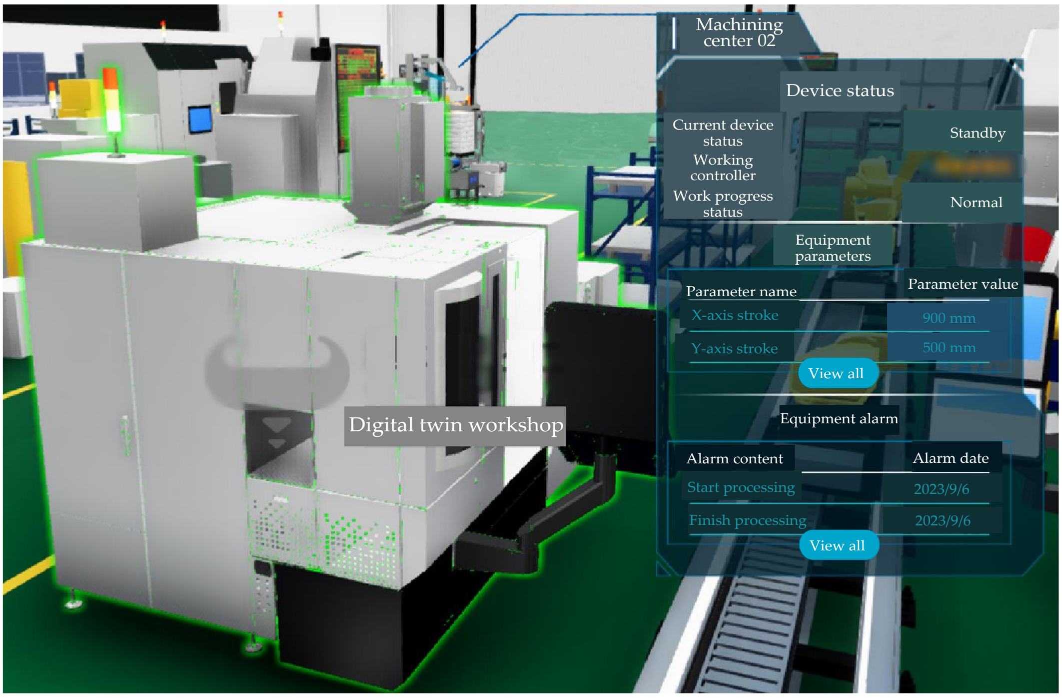

Figure 9. Running state of machine tool model on numerical control simulation platform.

To further verify the practicability of the system architecture and platform proposed in this paper, a ship processing production line is selected for popularization and application. The production line consists of a three-dimensional library, CNC cutting machines, CNC grinding machines, CNC milling machines, and welding robot equipment. The system diagram of the simulation platform for the ship processing production line is shown in **Figure 10**. The simulation platform can simulate the whole process of pipe processing. The results show that the simulation platform can realize synchronous mapping, production line simulation, and production scheduling optimization of the ship processing production line. Through the data collection of physical entities such as field CNC machine tools, the synchronous real-time mapping between the digital twin model and CNC machine tools is driven.

The simulation platform can simulate the production process and predict the order completion time by collecting the production time and calculating the production load. It is equivalent to adding a virtual manufacturing simulation system between the production planning system and the intelligent management and control system. A virtual manufacturing simulation system carries out virtual manufacturing before actual production. The simulation analysis results are transmitted to the production planning system. It transmits production planning information, process information, and execution strategy to intelligent management and control systems. The intelligent management and control system receives the production plan and process information from the numerical control simulation platform and transmits it to the equipment layer through the field control PLC. All twin equipment models can be updated and optimized in real-time according to manufacturing requirements. The interaction between twin models is realized by digital threads. The synchronous real-time mapping between physical manufacturing and virtual manufacturing is realized.

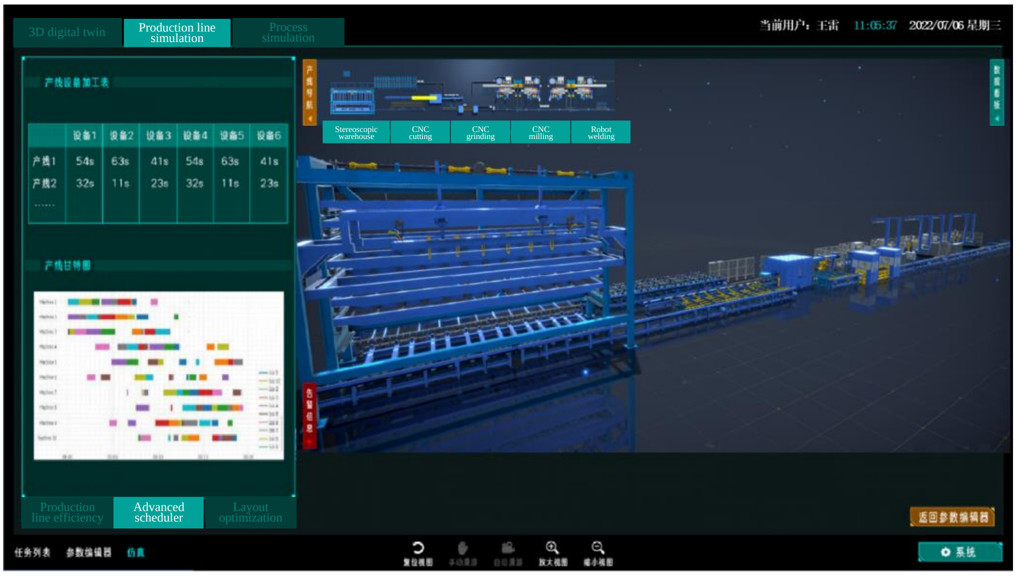

Figure 10. System diagram of the simulation platform for ship processing production line.

6. Conclusion

Research on the deep integration of machine tool manufacturing technology and new-generation information communication technology under vibration disturbance is of great significance for improving the intelligence level of CNC machine tools. Based on the industrial internet, the simulation of CNC machine tools in the workshop of discrete manufacturing enterprises under the influence of vibration is taken as the research background. According to the process and functional characteristics of the discrete industry, the system planning and design of the NC simulation platform are carried out. The digital twin model of the NC machine tool is constructed, and the data and model are mapped synchronously. The data integration and fusion are deeply analyzed and discussed. Through the integration of the NC machine tool simulation platform, the top-down data instructions can be issued accurately, and the bottom-up feedback information can be confirmed in time. The smooth implementation of the NC simulation platform improves the efficiency of production execution and provides strong support for the application of the NC simulation platform in all discrete factories. Nevertheless, the existing research has not considered data interaction and mapping in dynamic scenarios such as production line reconfiguration and customized production. It is difficult to restore the production status of discrete manufacturing workshops. Therefore, in future research, these related problems will be studied emphatically by combining artificial intelligence and the agent.

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