2021 IEEE 1st International Conference on Digital Twins and Parallel Intelligence (DTPI) | 978-1-6654-3337-2/21/$31.00 ©2021 IEEE | DOI: 10.1109/DTPI52967.2021.9540104

Research and practice of lightweight digital twin speeding up the implementation of flexible manufacturing systems

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***Abstract*—Parallel manufacturing in Industry 5.0 requires digital twin to digitize physical systems, building virtual models to open up channels connecting physical systems, information systems, and social systems, and transforming the physical models of the existing production environment to achieve two-way feedback of virtual and real is the current research direction. This paper proposes the modeling idea of lightweight digital twin, extracts core dimensions and performs digital virtual simulation, so as to quickly realize the complete process of two-way feedback, and realize a set of chess flexible parallel manufacturing production lines as a practice for the design of complete lightweight digital twin.**

***Index Terms*—parallel manufacturing, lightweight digital twin, flexible manufacturing**

I. Introduction

Throughout the development process of modern industry, five industrial revolutions can be divided. (1780) The first industrial revolution used water and steam power in the mechanized manufacturing process. (1870) Electricity entered the factory, driving the assembly line and mass production. (1970) Digital technology, including robots, began to enter the manufacturing process. (2011) In the era of interconnection, factories operated in their own way, and at this time the ”cyber-physical system” (CPS) technology was proposed. With the deep integration of the Internet, big data, cloud computing, artificial intelligence, and industrialization, the manufacturing industry is shifting to intelligent manufacturing, entering the fifth industrial revolution, or Industry 5.0. Compared to the CPS system of the fourth industrial revolution, the fifth industrial revolution further strengthened the integration of information and physical systems, and fully integrated industry and human society, forming a cyber-physical-social-systems (CPSS) and industrial intelligent networking. In this new model, humans will work with collaborative robots or ”cooperative robots” to guide the robots to complete their work and correct errors in the robot’s operation in time. Machines will perform the most trivial, repetitive and dangerous tasks, and people will use their complex and flexible brains to make high-level decisions: design products and processes.

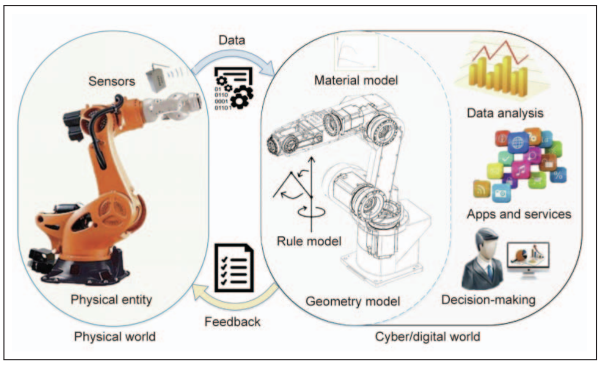

Fig. 1. CPS and DTs.

Digital twin technology plays an important role in the CPS of Industry 4.0, and is also an important technology that supports the realization of the three functions of CPSS of Industry 5.0, and has attracted the attention of scholars and researchers. The concept of twin originated from the National Aeronautics and Space Administration's "Apollo Project". With the rise of parallel manufacturing in Industry 5.0, digital twin is used in parallel intelligent manufacturing systems, which acts as a bridge between information systems, physical systems, and social systems, as shown in Fig. 1 [11]. By building digital twin models in digital systems, they reflect the physical system and The operating state of the actual model in the social system. The bidirectional feature of the digital twin can synchronize the model information in the physical system to the information system in real time, and at the same time, synchronize the reverse control information to the physical system based on the predictive information in the information system and the intelligent decision-making information of big data, thereby optimizing operational efficiency and effectiveness in the physical system.

As the industrial revolution promotes the development of industrial manufacturing, people have more diversified needs for the function and quality of products, and the concept of flexible manufacturing has emerged as the times require. The characteristics of the digital twin reverse control of the physical system can promote the implementation of the concept of flexible manufacturing. Reverse control optimizes and improves the production process, flexibly controls the production process of the physical system production line, and improves the agility of production.

II. Research Status

This year, people have conducted extensive discussions and researches on various aspects of digital twin, including research on the construction and application methods of digital twin in the workshop, and figures designed to provide services such as design complexity measurement, workload estimation, and change propagation prediction. The modeling method of multi-physical digital twin uses augmented reality technology to communicate layout information between virtual and real systems. In addition to research in high simulation and optimization, there is also research in the application of digital twin to enhance security. [14] - [19].

These studies are mostly about digital twin modeling methods and digital twin application scenarios. There are few researches on the actual flexible production system implementation plan. This article focuses on the rapid implementation of flexible manufacturing systems and proposes a lightweight digital twin modeling method. The design idea highlights the advantages of virtual control in the two-way nature of digital twin, grasps the core values of digital twin and flexible manufacturing, designs a flexible manufacturing system based on lightweight digital twin, and deploys them in the laboratory to realize a digital twin-based flexible manufacturing system. The prototype of the complete process of the flexible manufacturing concept.

In the follow-up content of this article, we describe the difficulties of the flexible manufacturing system based on digital twin, and then propose solutions to reduce the weight of digital twin, and introduce the specific implementation plan for deploying flexible manufacturing production lines based on lightweight digital twin in laboratories. Finally, it summarizes the challenges and future research directions of lightweight flexible manufacturing prototype research.

III. Problem Description

CPS, the physical information system of Industry 4.0, realizes the interconnection of things. Industry 5.0 it adds the concept of human-machine integration, and pays more attention to integrating artificial intelligence and human wisdom into industrial production processes. In these processes, it is required to realize the digitization of physical systems and the integration of virtual and real with virtual control of real. People choose digital twin to realize the main technology of digitization of physical systems. The twin idea was originally used to synchronize the production environment and the experimental environment through the backup of the spacecraft. The completeness of the twin is convenient for engineers to reproduce and find problems when an emergency occurs.

In the process of the twin idea to solve the virtualization of physical systems in industrial production through digitalization, the original completeness requirements are still used. Our expectation for digitalization will be as complete as possible. The completeness requirements of digital twin will increase the workload of the transformation of the existing production environment. On the one hand, it is necessary to add more sensors and other transformations for information acquisition, and a large amount of multi-dimensional information such as processing and assembly will be generated in the production system, and a large amount of dynamic multi-dimensional information must be fed back to the information system in real time. On the other hand, each component in the physical systems should open the control interface to make it possible that information systems control the physical systems. Here, the physical system component modules need to reflect the concept of flexible manufacturing. The flexibility and agility of flexible manufacturing can increase the complexity. In the actual implementation of the digital twin, the completeness of these two aspects has increased the challenge of the actual design and deployment of the digital twin.

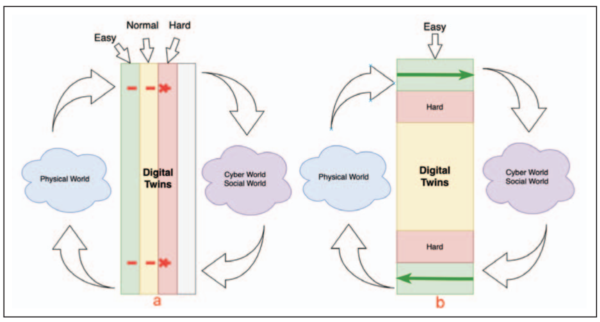

Fig. 2. a. general DTs, b. lightweight DTs.

This paper proposes the idea of lightweight digital twin, as shown in Fig. 2. The digital twin in parallel manufacturing are different from the goal when the twin concept was first proposed. The completeness of the virtual model for physical model simulation is not so vital at this stage. Of course, the final digital model is complete. It has an impact on the entire parallel manufacturing process.

In fact, the idea of lightweight digital twin is to change the problem from breadth-first to depth-first, multi-dimensional analysis and decomposition of the digitalization of the complete production process, focusing on the core modules of the production process, simplifying the digital dimension, and focusing on the main dimensions of the production process. The digitization of information enables the real-time dynamic feedback mechanism of single-dimensional information to be quickly designed and implemented.

The lightweight digital twin through single-dimensional information feedback and flexible control of the physical system reduces the transformation degree and design complexity of the digital twin application and actual flexible manufacturing, thereby accelerating the deployment of the prototype of the flexible parallel intelligent manufacturing system based on the digital twin . In the laboratory environment, we designed and implemented a prototype of a flexible parallel manufacturing production line system based on the idea of lightweight digital twin, combined with the concept of flexible manufacturing.

IV. System Design

A. Features

The intelligent chess production line designed in this paper uses lightweight digital twin design ideas to realize a parallel manufacturing system, as shown in Fig. 3. With the development of Industry 5.0, researchers have proposed a new intelligent manufacturing paradigm: parallel manufacturing, which integrates physical systems, cyber systems, and social systems. In the physical system, the chess production line contains a series of hardware equipment, mainly including 8 desktop robots, several sensors and cameras, and other auxiliary equipment. We complete the chess production process in the physical world through these hardware devices.

In the cyber system, the core dimensions of the physical system are virtualized through the lightweight digital twin, including the coordinates of the desktop robot's real-time pick-and-place operation, the joint angle of each manipulator, and the digital information captured by the sensors and cameras. The cyber system uses this information to analyze and model, generate artificial intelligence decisions from historical data and real-time data, and use it to reversely control the production process in the physical system.

After the cyber system receives the information fed back from the physical system, in addition to being used for artificial intelligence decision-making, it will also transmit information to the social system. The social system includes experts in various fields, who receive the information transmitted by the cyber system, and combine their professional experience and decision-making capabilities to supplement and optimize control methods. Finally, the experience of artificial intelligence and the experience of domain experts are combined to control the physical system. In the chess intelligent manufacturing production line, this process is reflected in the control quality of the cyber system to adjust the moving position of the robotic arm in real time when there is a quality problem, so that the chess pieces can be printed more accurately.

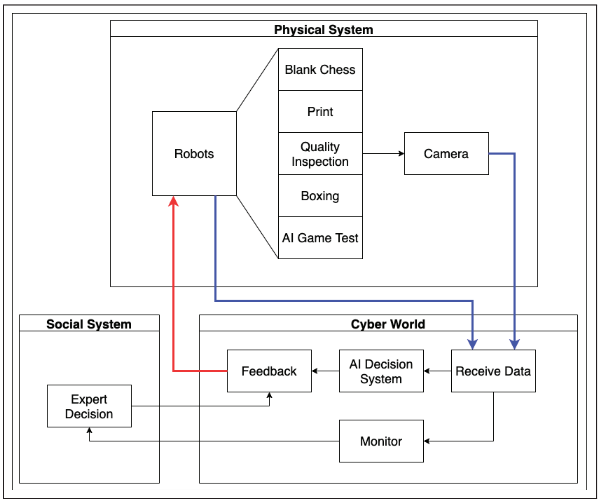

Fig. 3. Digital twin and parallel system design.

In the whole process, the closed loop of information is completed. The physical system transmits information to the cyber system, and the cyber system transmits to the social system. The control information of the cyber system and the social system is fused and fed back to the physical system. The information flow in this process is realized in the form of a lightweight digital twin. A complete information closed loop can take advantage of parallel manufacturing. The lightweight digital twin speeds up the process of this closed loop, forming a thin ring of information first, and then constantly expanding it.

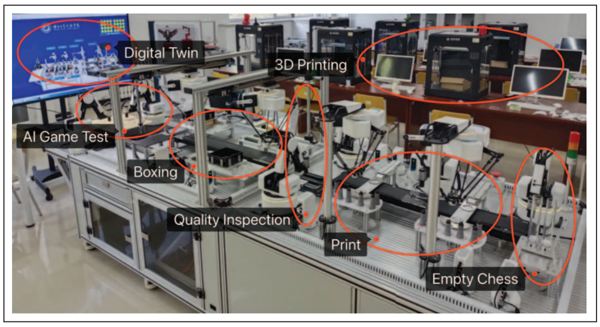

Fig. 4. production line prototype.

In a laboratory environment, we designed a prototype of a chess flexible parallel manufacturing production line system based on digital twin, as shown in Fig. 4. Through multiple robotic arms, we can complete the chess production process, including blank chess loading, red and black chess production, and chess quality. Test and assemble into boxes.

The starting point of the production line process is to prepare blank chess pieces. Blank chess pieces can be produced by 3D printing and users can customize chess pieces, issue personalized manufacturing instructions through the mobile terminal, which reflects the flexibility characteristics of flexible manufacturing. The next step is to print the chess pieces. According to user needs, different types and different numbers of chess pieces can be printed. The user can monitor the manufacturing progress in real time and adjust the production progress of the chess pieces. The current plan is to print chess pieces with limited position, and the upgraded version is to remove the limit and print flexibly through visual recognition. The next process is quality inspection. Take the image of the finished chess piece through the camera and transmit it to the quality inspection function module. The image recognition function based on deep learning screens the defective products, and controls the robotic arm for sorting processing, and the unqualified pieces will be overwritten and printed. In the upgraded version, the system trains and analyzes historical data during the process, and automatically adjusts according to the reasons for unqualified. Users can also receive real-time quality inspection result information in the monitoring system, and modify the motion parameters of the robotic arm at any time. Next, the production line will place the qualified chess pieces in order and pack them into boxes. Finally, the user can choose to hand over a complete set of chess pieces to the AI dual-machine game for demonstration and testing.

B. Overall Design

The overall design of the system can be explained from two aspects: one part is the design and construction of the hardware system, and the other part is the design and realization of the software system.

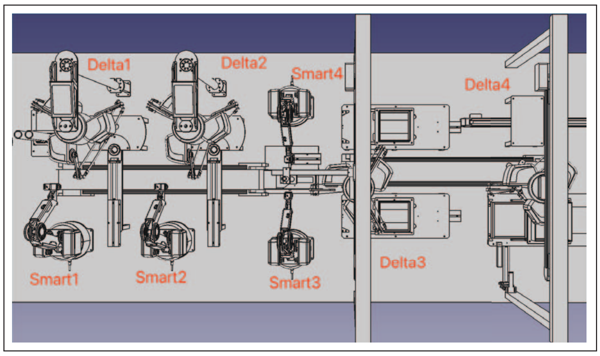

Fig. 5. hardware layout.

As shown in Fig. 5, The hardware system mainly includes 8 desktop robots (Smart1-4, Delta1-4), Smart1 and Smart2 place blank chess pieces, Delta1 and Delta2 print chess pieces, Smart3 and Smart4 throw away unqualified chess pieces, and Delta3 and Delta4 are arranged for packing.

The software system can be divided into the following modules, as shown in Fig. 6:

The process control module communicates with robots, sensors and camera through the serial port. It receives the real-time status of the robots and feed back data from sensors and the camera. The image is transmitted to the quality inspection module which judges whether the chess pieces are qualified

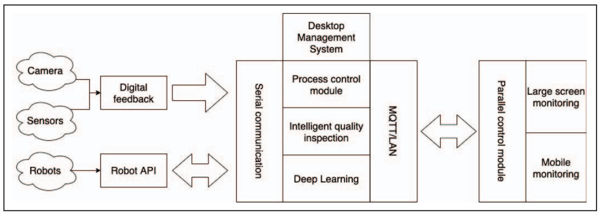

Fig. 6. software modules.

or not bases on deep learning. The core control module adjusts the robot's pick-and-place position according to the quality inspection results so that the printing quality of the chess pieces can be improved. The parallel control module communicates with the core control module through MQTT in the local area network, which provides remote monitoring functions, icon display and 3D display of digital twin.

V. System Analysis

In the design of flexible manufacturing concepts, we reflect the characteristics of flexible manufacturing by dynamically specifying the types and quantities of chess manufacturing in the parallel control module. In the design of the digital twin, by simplifying the digital information dimension of the digital twin, the digital dimension is concentrated on the quality control process of chess manufacturing. The digital model includes the final image information of the chess pieces and the movement coordinate information of the desktop robot, and the control dimension of the physical system. Through the control of the robot's moving coordinates, the bidirectional feature of the digital twin data flow is realized.

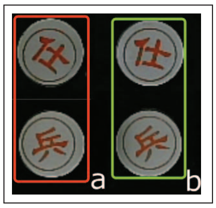

Fig. 7. a.defective products, b.qualified product.

To control the quality of chess pieces, as shown in Fig. 7, if the chess piece seal is offset from the center point, the coordinates will be adjusted to change the position of the chess piece seal, thereby adjusting the printing quality of the chess pieces in real time. The effect of this real-time adjustment reflects the efficiency of parallel manufacturing in improving and optimizing production process control. The traditional CPS system could find deviations in the printing quality of chess pieces, but it requires engineers to adjust the printing coordinates of the desktop robot after analyzing the results to optimize the production line production process. Based on the parallel manufacturing of the digital twin, it will be based on the data information of the historical movement status of the desktop robot. Analyze and optimize the adjustment strategy and improve the production process in real time, which greatly improves the efficiency of improving the industrial production process.

VI. Summary

Regarding the modeling method of digital twin technology, this paper proposes a lightweight plan. The lightweight digital twin analyzes the digital dimension, selects the core dimension information of parallel manufacturing ahead for digital simulation, and improves the entire production process through reverse control, reflecting the core value of the digital twin in parallel production, improve efficiency of the production line. Through the realization of the lightweight digital twin, the flexible manufacturing process can be realized quickly, and then according to the production needs, the expansion of other dimensions of digital twin can be implemented gradually, and the entire flexible parallel production line can be agile and iteratively improved. Digital twin transformation of the horizontally expanded production line.

Acknowledgment

This work was supported in part by the National Key Research and Development Program of China (No. 2018YFB1702700), National Natural Science Foundation of China under Grants U1909204, 61773381 & U1811463; Chinese Guangdong's S&T project (2019B1515120030, 2020B0909050001). Hunan province science and technology program 2018GK1040. CIE-Tencent Robotics X Rhino-Bird Focused Research Program No.2020-01-005.The development team and application case partners had put a lot of effort into the implementation of the project, and the authors, Xiaodong Zhang, Bin Hu, Gang Xiong, Xinjie Liu, Xisong Dong, Dongjia Li etc., would like to thank them.

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