Real-time Modeling and Simulation Method of Digital Twin Production Line

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***Abstract*—In view of the low efficiency of production line modeling method and the poor quality of the production line model, this paper proposes the concept of digital twin production line by analyzing the simulation & modeling of production line and digital twin, and analyzes the composition of digital twin production line. Then the real-time modeling and simulation method of digital twin production line is proposed. Finally, the effectiveness of the proposed method is verified by taking a product assembly line as an example.**

Keywords—digital twin; production line; modeling and simulation

I. INTRODUCTION

The concept of digital twin was proposed by Professor Michael Griffith of the University of Michigan, USA [1]. Digital twin has been applied and validated in some engineering areas currently. For example, the US Department of Defense proposes the use of digital twin technology for the health maintenance and support of aerospace vehicles [2]. Siemens in Germany applied digital twin to the design and production process of Siemens industrial equipment [3-4].

Modeling and simulation is the key technology in manufacturing, and it has the incomparable importance for improving products and processes, reducing response time and reducing product costs [5]. Modeling and simulation technology can be roughly divided into three types: 1) using various advanced computer programming languages, such as C, C++, Java, etc.; 2) using simulation programming languages, such as GPSS/H, SIMAN/V and SLAM; 3) using commercial professional simulation software, such as Flexsim, AutoMod and Plant-Simulation. The above methods still have some shortcomings in the efficiency and quality of simulation and modeling, and the accuracy and effectiveness of the model. Moreover, these methods can only be used in the design stage, which cannot support the combination of production line logic simulation with products, process flow and resources.

In view of the above problems, this paper studies the real-time modeling and simulation method of the digital twin production line based on the analyzing the definition and composition of the digital production line, and realizes the deep integration of the physical production line and the digital production line model in the virtual world through the digital twin production line.

II. DEFINITION OF DIGITAL TWAIN PRODUCTION LINE

Digital twin production line refers to an intelligent production line system consisting of a physical production line, a digital production line, an intelligent sensing system, and an intelligent decision-making system. It realizes integrated management of production factors, production equipment, production data, and production processes through correlation and integration.

The digital twin production line uses not only in the design and planning process, but the entire life cycle of the production line. Before the construction, the simulation of the production line and the transfer of real parameters to the actual production line can effectively reduce errors and risks. After the production line was constructed, the daily operation and maintenance interact through the digital twin model, not only to show the real state of the production line, but also to diagnose the abnormality and predict the future state of the production line in the physical world.

III. COMPOSITION OF DIGITAL TWAIN PRODUCTION LINE

As showed in Fig.1, the digital twin production line consists of four parts: physical production line, digital production line, intelligent sensing system and intelligent decision-making system.

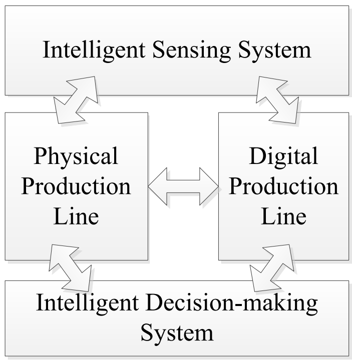

Fig.1 Compositions of digital twin production line

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A. Physical Production Line

The production line in the physical world mainly composes three parts: 1) production equipment: such as CNC machine tools, industrial robots and controllers, material automated transportation systems and inspection equipment, etc. Production equipment work together to complete the production tasks; 2) production materials: Product parts, semi-finished products, outsourcing parts and corner residual materials generated during the production process; 3) Production personnel: operators, maintenance personnel, safety personnel, etc.

B. Digital Production Line

The digital twin production line in the virtual world consists of four parts: 1) system model used to analysis and represent the sequence, concurrency, randomness and conflict in the production line, simulate the entire production system simply and intuitively, achieving a rational planning of the production line; 2) geometric model means the real-time data driven by the production site to dynamically reconstruct the line model, so that the model can display the production status, working status, and personnel position of the production line in real time; 3) Process model used to show the process flow of the production line and the highly abstracted model driven by the production personnel through real-time data, so that the model can master the production process intuitively; 4) simulation model used to display the deformation, temperature, vibration, collision and other information of the key parts of the production equipment, and predict the future operation status of the equipment through the data information, so that the model can predict the situation of the production equipment early.

C. Intelligent Sensing System

The intelligent sensing system includes intelligent sensor components such as speed sensor, position sensor, pressure sensor, temperature sensor, and RFID reader. The function is to collect data such as the production stage of the production line, the operation data of the production equipment, the position information of the production personnel, and the like. The dynamically changed data is filtered, processed and passed to the digital twin model, which drives the dynamic reconstruction of the model to show the real production status, that can helps the production personnel to diagnose and locate the fault.

D. Intelligent Decision-making System

The intelligent decision-making system can store various data and information collected from the production site. The using of the existing data could discover the safety hazards in the production equipment, and plan or maintain in advance by simulating and predicting the future production state through deep learning and analyzing the simulation model. The intelligent decision-making system assists the production staff in the formulation of production decisions and the optimization of the production process.

IV. REAL-TIME MODELING AND SIMULATION

A. Fusion of Physical Production Line and Smart Component

Real-time acquisition of key information, such as process status, work group status, equipment status and material status, is achieved by accessing intelligent sensing components such as displacement sensors, force sensors, vision sensors, and temperature sensors. Sending data such as temperature, vibration, collision, load, and position in the production line to the digital twin model keeps the twin model consistent with changes in the work environment.

B. Multi-level Model Association Fusion

As showed in Fig 2, by constructing a digital twin production line model, models are built at four different levels: system, process, geometry and simulation. Through the association and fusion of the models, multiple models complement each other to achieve a close connection between the physical production line and the digital production line. The key to realizing multi-model association and fusion lies in constructing the parametric model and parameter-driven mechanism of entity objects.

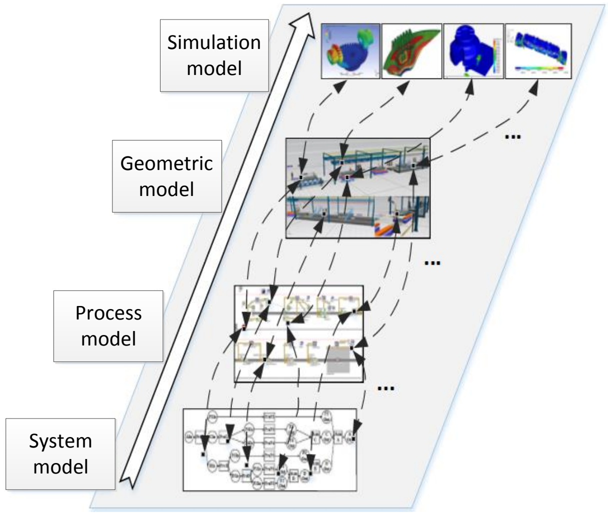

Fig.2 B. Multi-level Model Association Fusion

C. Production Data Fusion and Processing

There are many types of sensors used in the production line. Each sensor has certain conditions of use and sensing range, and can only give information about the environment or part or side of the object. In order to make effective use of this information, it is necessary to integrate production data in some form. Through the data fusion, the production line digital twin model is used for simulation prediction, the production status is analyzed in real time, and the independent decision is made to seek the optimal production plan.

D. Data Driven Real-time Modeling and Simulation

According to the collected relevant data, engineering personal can determine the production process, the size, composition and layout of the production system, including the type and quantity selection and layout of the processing equipment, the selection and design of the logistics system, the determination of the auxiliary equipment, etc. As the consequence, the production line has been built. The parametric model of the entity object is simulated and analyzed, and the production line model is adjusted and optimized according to the simulation results. The modeling and simulation process of digital twin production line is showed in Fig3.

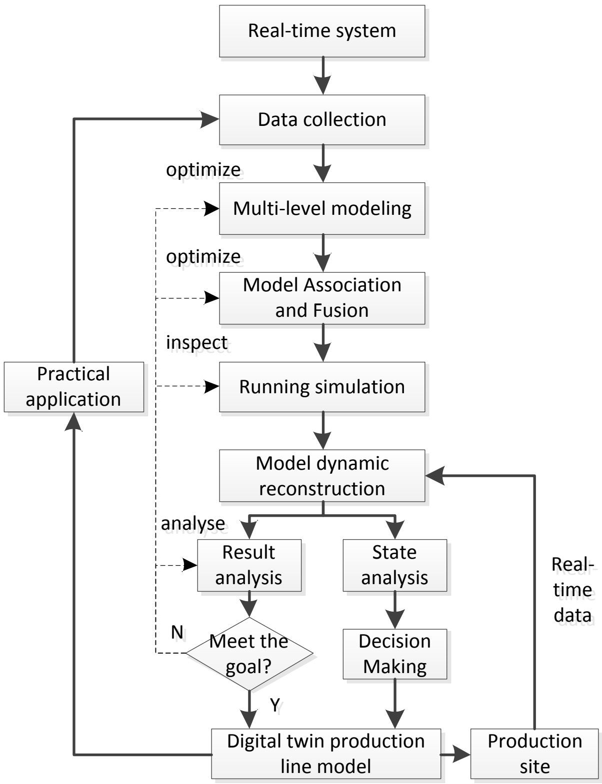

Fig.3 Modeling and simulation process of digital twin production line

V. IMPLEMENTATION AND EVALUATION

In order to visually describe the real-time modeling and simulation process and verify the advantages of digital twin production line, this paper uses a simple assembly line as an example as showed in Fig4.

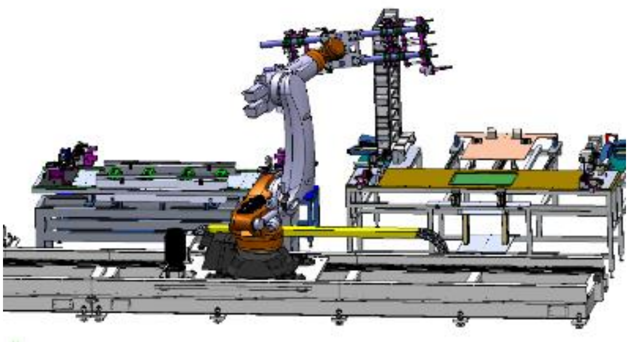

Fig.4 Assembly line

The assembly line includes a six-degree-of-freedom series robot, a translation guide rail, a rack, a conveyor belt, a part to be assembled, and the like, which are horizontally moved. The digital twin production line model can be dynamically reconstructed based on models of multiple levels in the real-time data-driven graph. Taking the robot in the figure as the research object, the realizing of the real-time modeling and simulation of the production line is showed as follows.

The five joints of the robot have an angle sensor built in, the wrist end has a built-in pressure sensor, and the bottom mobile chassis is equipped with a speed sensor and a position sensor.

When the robot in the production line completes the assembly work, the sensing component connected in the production line detects the dynamic data. Then the intelligent decision system analyzes the acquired sensing data, and traverses the parameter list to the system model, the process model, the geometric model, and the simulation model. In the inspection model, there is no such parameter. Under the driving of this real-time data, the serial robot model is dynamically reconstructed according to the traversal result.

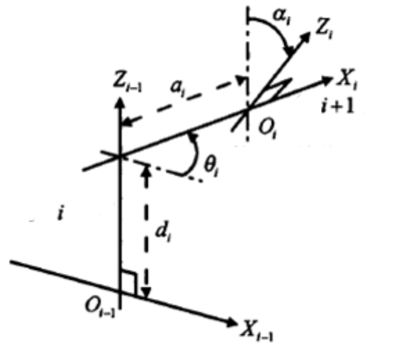

Fig.5 Coordinate system of robot links

Figure 5 shows the robot joint link coordinate system, where θ_i is the joint variable, d_i is the link offset, a_i is the link length, and α_i is the link angle; the relative position matrix of the link i relative to link $i-1$ is the coordinate system is [6]:

$$ {}^{i-1}_{\ i}T = Rot(x_{i-1},\alpha_i)Trans(x_{i-1},\alpha_i)Rot(z_i,\theta_i)Trans(z_i,d_i) \quad (1)$$

$$ {}^{i-1}_{\ i}T = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -d_i s\alpha_{i-1} \\ s\theta_i s\alpha_{i-1} & c\theta_i c\alpha_{i-1} & c\alpha_{i-1} & d_i c\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

In the relative position matrix, c and s represent cos and sin respectively. When the six-degree-of-freedom robot in the production line works normally, the changing parameter is the angular displacement of the joint position, and other parameters are fixed structural parameters. Assuming that the robot does not shift and only completes the assembly work by the arm rotation, when the robot rotates around the Y axis as a whole, the intelligent sensing system acquires the sensing signal R01 through a resolver (an angular displacement sensor) installed at the first joint position of the robot. The intelligent decision-making system processes the acquired sensor data to obtain angular displacement, and determines there is no such parameter in the system model and simulation model after analysis, but included in the geometric model and the process model.

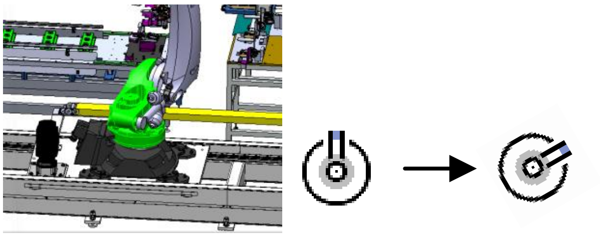

Fig.6 Dynamic reconstruction of geometric model and process model

Therefore the constraint relationship in the angular displacement drives geometric model changes. The variation angle of the matching angle between the first joint and the base of the robot is as showed in Fig. 6. At the same time, the angular displacement will also drive the process stage in the process model to be updated. Since the robot in the process model is highly abstracted, only the rotation of the icon can be used to indicate the change of the process stage. Therefore, the production personnel can grasp the real-time state of the serial robot in the production field directly through the reconstruction of the geometric model and the process model.

VI. Conclusions

Through in depth research on digital twin, this paper puts forward the concept of digital twin production line, expounds its composition and construction method, and proposes a real-time modeling and simulation method for digital twin production line. The effectiveness of the proposed method is verified by taking an assembly line an example. In the future, we will further study the intelligent control of the digital twin production line through the digital twin model, and strive to completely solve the real-time visualization and intelligent control of the production line.

References

[1] Grieves M, “Digital twin: Manufacturing excellence through virtual factory replication,” White paper, pp.1-4, 2014.

[2] Tuegel E J, Ingraffea A R and Eason T G, “Reengineering Aircraft Structural Life Prediction Using a Digital Twin,” International Journal of Aerospace Engineering, pp.1-14, 2011.

[3] Waurzyniak P. “Siemens PLM Software Focuses on Manufacturers' Teamwork, Digital Twins,” Manufacturing Engineering, vol.161, pp.24-31, 2018.

[4] Talkhestani B A , Jazdi N and Wolfgang Schlögl, “A concept in synchronization of virtual production system with real factory based on anchor-point method,” Procedia Cirp, vol. 67, pp.13-17, 2018.

[5] Zhou Hong, Deng Xiuquan and Gao Dehua, “Production System Modeling and Simulation,” Mechanical Industry Press, 2012.

[6] Siciliano B, Khatib O. “Springer Handbook of Robotics,” Springer Berlin Heidelberg, 2008.