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Research on Assembly Process Simulation of Construction Machinery Arm Based on Digital Twin †

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Abstract: The construction machinery arm is the key component of construction machinery to complete the operation task; its assembly link directly affects the product quality and operational performance of the whole machinery. To solve the problems of low assembly efficiency and the inability to fully reflect the assembly process indexes and product characteristics in the traditional construction machinery arm assembly, this paper studies assembly process modeling and simulation for the construction machinery arm based on assembly sensing data and digital twin. By extracting and processing the assembly resource data and field measurement data of the machinery arm, the assembly process information database under the digital twin environment is constructed, which lays the foundation for the virtual assembly model construction of the machinery arm. Through the real-time data interaction between virtual space and physical space, a complete assembly of digital twin spaces is formed. Finally, taking the assembly line of an excavator armed as an example, it is shown that the digital twin-based assembly simulation can monitor the assembly process in real-time and optimize its configuration to improve assembly efficiency. Therefore, an effective closed-loop feedback mechanism is constructed for the whole assembly process of the construction machinery arm.

Keywords: assembly simulation; digital twin; sensing data; data interaction; construction machinery arm; excavator

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1. Introduction

The mechanical arm is an important part of working devices for various large-scale construction machinery. Its structure is complex and requires strict manufacturing accuracy, which has a very important impact on the overall performance of mechanical products. The construction machinery arm assembly is the most important part of the manufacturing process of the working device, which is required to have good working performance under the condition of satisfying reasonable structure size and shape [1]. The current construction machinery assembly organization is still based on traditional centralized fixed assembly and has the following problems: the key process control points are not in place; the degree of automation is backward; the assembly process method rarely considers the physical size deviation and position errors that appear in the actual manufacturing. Meanwhile, the related equipment and tools are not highly mechanized and intelligent [2]. In terms of tools, in addition to mechanized transportation in the final assembly of traditional construction machinery, the rest of the final assembly is still carried out in the form of workshop cranes, forklifts, or manual handling, which is labor-intensive and has not been fully automated.

To solve the problems in the assembly work of construction machinery products, this paper applies digital twin technology on the assembly process of the construction

machinery arm. By constructing a virtual model of the entire assembly production line and a cyber–physical fusion system, the virtual assembly of the construction machinery arm is realized. Analyzing the design of each part of the construction machinery arm is reasonable or not in the early stage of the assembly process [3]. Once the problems are found, they can be adjusted in time to improve the efficiency and quality of new product development.

2. Assembly System Architecture of Construction Machinery Arm Based on Digital Twin

Given the above problems in the field of traditional construction machinery assembly, this paper builds a digital twin-based construction machinery arm assembly process modeling and simulation architecture and then applies digital twin technology in the field of construction machinery arm assembly based on the core ideas and key technologies of digital twins [4]. First, this paper establishes a product process model in a three-dimensional environment and builds a complete set of assembly process planning documents based on the technical requirements of the model and the actual on-site assembly requirements [5].

The process execution instructions and process information in the physical space can be visualized through a mobile terminal and the assembly process planning of the virtual digital space is guided through the information channel interface under reasonable collection and processing. In the assembly simulation process, the assembly site process flow is visualized and the pros and cons of the plan are evaluated based on virtual reality technology [6]. The construction machinery arms assembly system architecture based on the digital twin is shown in Figure 1.

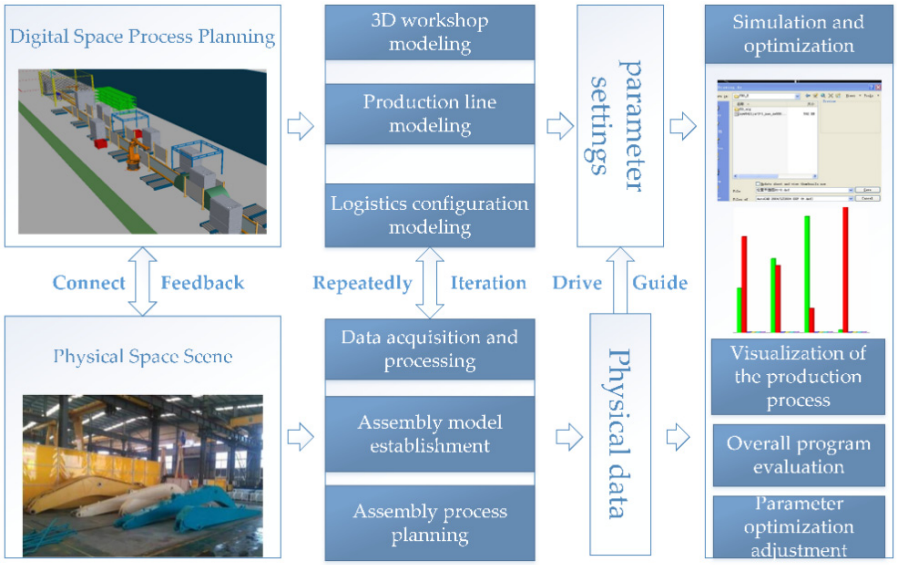

Figure 1. A Digital Twin-Based Architecture for Construction Machinery Arm Assembly.

3. Sensing Data Acquisition and Digital Twin Assembly Model Construction

3.1. Sensor-Oriented Digital Twin Data Acquisition and Processing on Assembly Site

Field measurement data is a collection of static data collected by coordinate measuring instruments and laser trackers and dynamic data collected by sensors and embedded systems [7]. The dimension information, assembly process information, and dimensional tolerance information of the construction machinery arm provide basic data support during the construction of the machinery arm assembly model and assembly process. Figure 2 presents classification and expression of digital twin data for construction machinery arm assembly [8].

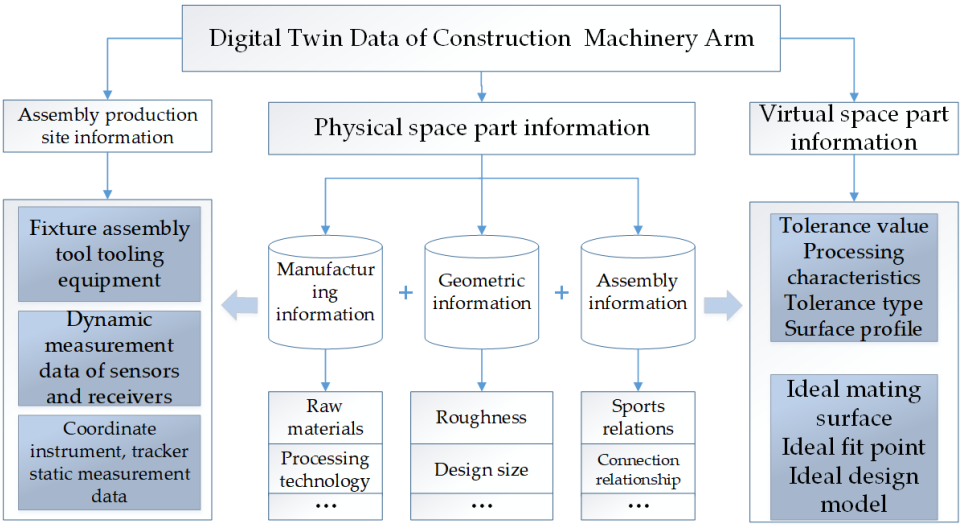

Figure 2. Classification and expression of digital twin data for construction machinery arm assembly.

Through human–computer interaction, hardware collection terminal, and sensor data acquisition methods, the data in the assembly production process of the construction machinery arm, including classification, preprocessing, and other related processes, are collected to simulate and optimize the design plan [9]. For example, data are acquired by scanning and sensing the surface of the part to obtain the dimensional data that characterizes the feature of the part and supports the construction of the digital model; most of the physical information is obtained through the experimental method, and the relevant performance index parameters are obtained under different environments and different loads, such as the metal fatigue test method, tensile test method, etc.

Data processing mainly uses modern sensors, measuring instruments, embedded systems, and other equipment to measure the surface characteristics of parts. Then, the collected data is processed in combination with computer technology [6,10].

3.2. Construction of Digital Twin Assembly Model Based on Sensor Measurement Data

The core of the digital twin is to combine the actual assembly conditions of the production site with a large amount of data and information in the physical manufacturing process to construct a virtual model corresponding to the assembly site, which is shown in Figure 3.

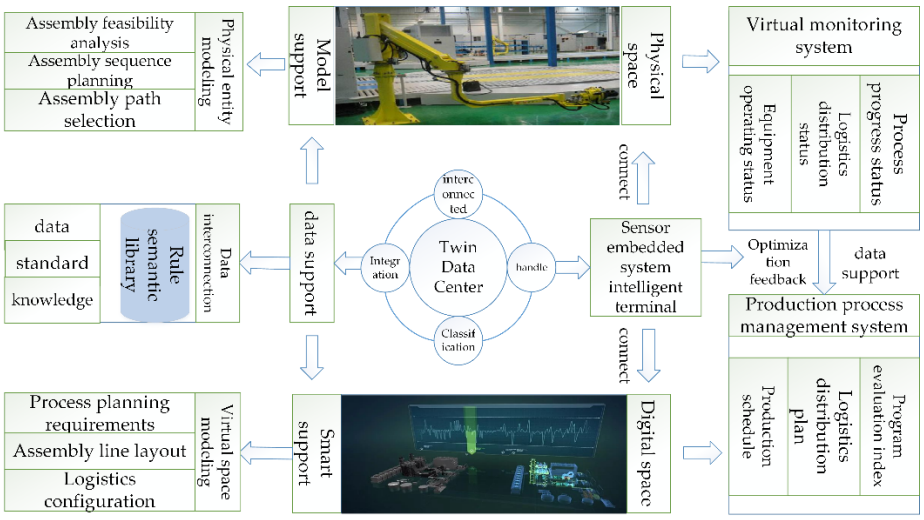

Figure 3. Global modeling of digital twin assembly space.

Compared with the traditional assembly process, virtual assembly based on digital twins mainly includes virtual space modeling and a data interconnection mechanism between the production site and the virtual model. Among them, the virtual space modeling establishes a virtual entity mapping configuration model that is completely consistent with the physical space according to the mapping logic to construct a multi-dimensional and multi-scale virtual manufacturing space [11]. The data interconnection mechanism between the production site and the virtual model is real-time sensing and integrated sharing of information in the intelligent manufacturing assembly process and the manufacturing result feedback process are integrated into a self-responsive whole through an appropriate data interface.

4. Assembly Process Simulation of Construction Machinery Arm Based on Digital Twin

Take the assembly line layout of an excavator's construction machinery arm as an example, and establish a simulation model of the production line in the Plant Simulation of Siemens software [12]. The construction machinery arm assembly adopts the principle of decentralized assembly, which can improve the parallelism and assembly efficiency of assembly to a certain extent [5]. The entire construction machinery arm assembly production line is divided into multiple different assembly areas, and the assembly process flow is simplified, as shown in Figure 4.

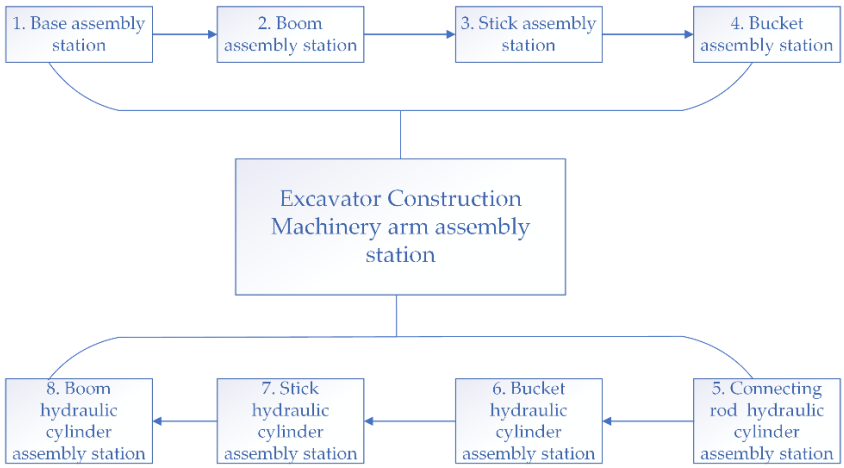

Figure 4. Assembly production flow chart of an excavator arm.

To reflect the complete information of the construction machinery arm assembly, the content of the virtual simulation modeling is divided into three parts, and the simulation process is shown in Figure 5.

- Modeling of the mapping relationship between physical space and virtual space. According to a reasonable logical setting, a virtual simulation space relative to the actual physical space is constructed in the software, and the requirements for the site elements of the excavator arm assembly are initially established [7,13].
- Information flow interconnection modeling between physical space and virtual space [14]. Configuring intelligent equipment for the parts to be assembled to complete process execution, equipment working condition data collection, environmental data collection to realize the automated execution, and control of the assembly process.
- The establishment of a virtual monitoring visualization platform [8,15]. A human–computer interaction visualization interface is provided to facilitate workshop managers to understand the manufacturing process, logistics distribution status, equipment operation status, and production data display in real-time.

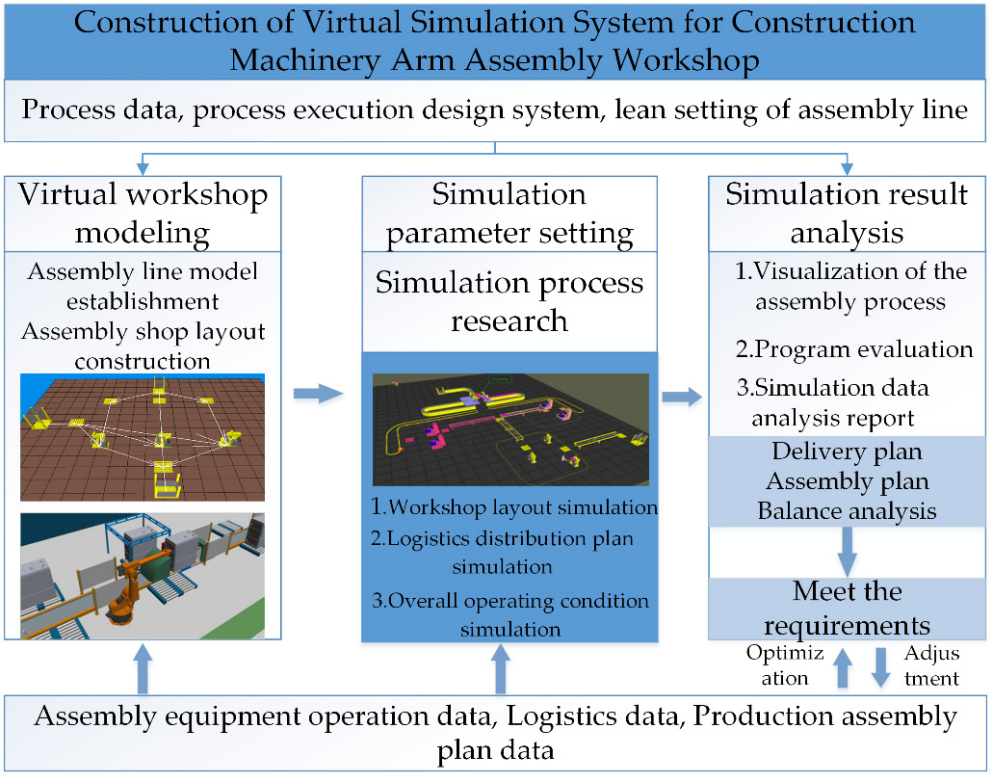

Figure 5. Assembly simulation flow chart of construction machinery arm.

5. Conclusions

This paper proposes a digital twin-based assembly process modeling and simulation method for construction machinery arm utilizing sensing data acquisition and management. By analyzing the assembly process characteristics of the machinery arm, an assembly system architecture of the construction machinery arm based on the digital twin is designed. From the perspective of assembly accuracy, the assembly sensing information is classified and processed, the data association in the assembly system is studied, then the assembly process information database under the digital twin environment is constructed. Additionally, the assembly line simulation of an excavator's arm is constructed in the software of Plant Simulation to connect the physical space and the digital space through the sensor part. Simulation analysis results show that this method can effectively identify assembly process problems, improve assembly quality and efficiency, and provide a feasible idea for the intelligent assembly of construction machinery under the background of intelligent manufacturing.

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