Quality control mode of intelligent assembly workshop based on digital twin

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Abstract: Intelligent assembly workshop technology based on digital twin is a potential way to realize intelligent manufacturing. Aiming at the complex assembly process and low assembly quality in the complex product assembly workshop, the research on the quality control mode of intelligent assembly workshop based on digital twin was carried out. On the basis of real-time collect of resource location information, assembly process information and assembly quality information by using the quality control mode, the Markov method and Manhattan distance algorithm were used to realize assembly process and quality control in assembly workshop. Finally, taking an aircraft wing assembly workshop as an example, the prototype control system of intelligent assembly workshop is applied and verified to provide a technical approach for improving assembly quality and realizing assembly workshop real-time and dynamic control.

1. Introduction

With the rapid development of Internet of things, intelligent sensing technology, information physical fusion and other technologies, the technological revolution as the core of the information technology is set off. Countries around the world have successively introduced their own advanced manufacturing development strategies and have looked for new ways to achieve breakthroughs in manufacturing [1]. For example, Britain's industry 2050, America's "advanced manufacturing" strategy, Germany's industry 4.0 strategy and made in China 2025, all aim to realize the interconnection and intelligent operation between the physical world and the information world with the help of the new generation of information technology, so as to realize intelligent manufacturing [2].

In 2003, professor Grieves first proposed the concept of digital twin in the course of product life cycle management at the University of Michigan [3]. A large number of researches have been carried out in digital twin-driven product optimization design, life cycle management, complex system control and other aspects by domestic and foreign scholars [4], and its concept is in the process of continuous
improvement and development. At present, the relatively accepted concept is defined by Beihang University and Beijing institute of Technology. A digital twin is a virtual model that uses digital technology to create a physical entity, with the help of data to simulate the characteristics, behavior, formation process and performance of physical entities in the real environment, the ability of physical entities can be expanded through virtual and real interaction feedback, data fusion analysis, decision iterative optimization, accurate and efficient execution and other means [5-6].

In recent years, the concept of digital twin has been in hot demand, and has increasingly become a representative of wisdom in various fields from manufacturing to industry, from military to people's livelihood. Tao Fei et al. from Beihang University explored the concept of Digital Twin shop-floor (DTS), designed the composition and operation mechanism of DTS and described four characteristics and five key technologies of DTS, which provide the basic theoretical support for the application of digital twin in manufacturing[7-8]. Behrang Ashtari Talkhestani et al. [9] of the University of Stuttgart proposed a digital twin modeling method based on model fusion. A complex virtual entity is constructed by combining a variety of mathematical simulation models, and an anchor point based virtual entity calibration method is proposed. Zheng Yu et al. [10] of Shanghai Jiao Tong University put forward a full-parameter digital twin implementation framework. The digital twin is divided into three layers: the physical layer, the information processing layer, and the virtual layer. Its application is realized based on the data acquisition, transmission, processing, and matching processes. Sun Huibin et al. from Northwestern Polytechnical University [11] studied the assembly technology of digital twin-driven aeroengine, discussed its composition, function and process, and analyzed the key technologies of assembly process control, part selection, assembly operation guidance, assembly clearance control, assembly technology state control in detail, which provided theoretical basis and technical reference for the research and system development of digital twin-driven aero-engine assembly technology. Nowadays, digital twin technology has been applied in aircraft and spacecraft in China [12-13], but digital twin technology is still in the stage of exploration, there are still many problems to be solved. For example, there is no set of accurate theory about digital twin technology. It is difficult to guarantee the timeliness, synchronization and reliability of multi-source heterogeneous data by the existing sensing technology [14]. The huge data information in the digital twin is in an open environment with uncertain rules, and the decision objectives are easy to conflict, so it is difficult to establish a decision simulation model [15].

Aiming at the problems of mixed flow assembly, low assembly quality and low assembly efficiency in the current aircraft wing assembly workshop, the research on the quality control mode of intelligent assembly workshop based on digital twin was carried out. This mode had realized the collection of resource location information, assembly process information and assembly quality information. On this basis, Markov method and Manhattan distance algorithm were used to realize assembly process and quality control in assembly workshop. Finally, taking an aircraft wing assembly workshop as an example, the prototype control system of intelligent assembly workshop is applied and verified to provide a technical approach for improving assembly quality and realizing assembly process control of complex equipment product.

2. Design of intelligent assembly workshop technology architecture based on digital twin

In Figure 1, the intelligent assembly workshop technology architecture based on digital twin is divided into five parts, namely real assembly workshop, digital twin assembly workshop, intelligent gateway, assembly workshop twin data and assembly workshop control system [16]. The real assembly workshop includes materials, equipment, personnel and products. The digital twin assembly workshop mapped by real assembly workshop, including workshop model, station model, equipment model and rules[17]. Intelligent gateway can realize real-time mapping, fusion and interaction between measured data of real assembly workshop and twin data of digital twin assembly workshop. Assembly workshop twin data is the collection of real assembly workshop and digital twin assembly workshop information, including historical data, real-time data, measured data, simulation data, etc. It provides data support for the assembly workshop control system. Finally, real-time, effective and accurate information is transmitted
to the assembly workshop control system, which can judge, predict and provide solutions based on complete information data and clear mechanism through Internet of things, multi-dimensional simulation and other technologies. The real-time data collected in the real assembly workshop are transmitted to the digital twin assembly workshop through data interface and field bus, and the digital twin assembly workshop uses these real-time data for simulation and analysis. Then the real-time data of the real assembly workshop and the simulation data of the digital twin assembly workshop are transmitted to the database through the intelligent gateway and the data protocol to form the assembly workshop twin data. Assembly workshop control system calls the assembly workshop twin data to judge the feasibility of further assembly according to the current assembly state. If further assembly is possible, the assembly workshop control system will send the continue assembly command to the real assembly workshop. Otherwise, it will send the stopping and adjusting assembly operation command to the real assembly workshop. After the real assembly workshop is stopped and adjusted assembly operation, the assembly workshop twin data are again called by the assembly workshop control system. The assembly workshop control system continues to judge and predict the feasibility of further assembly until the qualified product is assembled.

![Diagram](image)

**Figure 1. Intelligent assembly workshop technology architecture based on digital twin.**

### 3. Intelligent assembly workshop composition based on digital twin

Figure 2 illustrates a composition of intelligent assembly workshop based on digital twin [18]. Intelligent sensing, signal processing, Internet of things and other technologies are used to collect real-time assembly process data of the real assembly workshop. The collected data are expressed as a digital signal recognized by the computer and network, then transmitted to the digital twin assembly workshop for simulation and analysis of the assembly state. Through the mapping and interaction of real assembly workshop and digital twin assembly workshop, real-time monitoring, control and decision-making of the whole elements and the whole process of the assembly process in the aircraft wing assembly workshop are realized, providing effective support for improving the assembly quality and assembly efficiency of complex equipment products.

1. Real assembly workshop: it is a collection of assembly resources in the production workshop, mainly composed of materials, assembly frame, tooling, instrument equipment, European crane, trailer, worker, etc. Both the modeling of the digital twin and the decision of data analysis should be based on the real assembly workshop, otherwise, all the judgment and execution of the digital twin are wrong [19].
(2) Digital twin assembly workshop: it is the set of physical model established by the assembly resources in the real assembly workshop, behavior rules, etc. Multi-dimensional digital twin model is used to simulate the real assembly workshop.

(3) Assembly workshop twin data: it is the collection of real assembly workshop and digital twin assembly workshop information. During the assembly process of real workshop, huge multi-source and heterogeneous information will be generated, including the location information of assembly resources, assembly quality information of key parts, assembly progress information and other information. Through Radio Frequency Identification (RFID), the assembly station of the workshop was located in the area, and Ultra Wide band (UWB) technology is used to precisely locate the assembly resources, logistics track and personnel distribution of the workshop [20]. Intelligent tools such as Internet of things screwdriver and Internet of things wrench are used to collect force, torque, displacement and other information generated in the assembly process. Intelligent sensor devices such as light sensor monitoring label, current monitoring label and industrial sensor are used to monitor the equipment in real time. In the virtual workshop, Markov prediction method and Manhattan distance algorithm use the above data to simulate and analyze the assembly state and generate the simulation data. Finally, the measured data of the real assembly workshop and the simulated data of the digital twin assembly workshop constitute the assembly workshop twin data.

(4) Assembly workshop control system: Through AI monitoring platform, Internet of things platform, upper enterprise-level software, etc., assembly workshop twin data are used to control assembly process, assembly quality.

Figure 2. Intelligent assembly workshop composition based on digital twin.

4. Intelligent assembly workshop management and control mode based on digital twin
Assembly workshop quality control mainly includes two aspects. Firstly, the twin assembly workshop accurately grasps the current state of the assembly process data and predicts the future state of the data. The assembly workshop control system adjusts the assembly process according to the predicted result to avoid the rework caused by wrong assembly and missing assembly. Secondly, the twin assembly workshop accurately grasps the real-time assembly quality data. The assembly workshop control system gives early warning to the parts that do not meet the assembly quality requirements and sends the second assembly order to the real assembly workshop, so as to guarantee the assembly quality in real time and overcome the problem of lagging assembly quality monitoring.

Markov prediction method is mainly used to analyze the future variation trend of discrete random processes. This method uses the current state of a variable to predict its future state, and the prediction
process has nothing to do with the previous state, only with the current state [21]. The output of the wing is small, so there is little traceable historical assembly process data [22], and the significance of digital twin technology is timeliness, which is to analyze the current state and predict the future state. Therefore, the Markov method which is not strongly dependent on the data of historical assembly process is more suitable for the prediction of assembly state.

The positioning systems are divided into hardware and software. The hardware mainly includes base station, intelligent gateway, positioning label, light sensing monitoring label, current monitoring label and so on. The software mainly includes the traditional angle of arrival algorithm and the time difference of arrival algorithm. The positioning systems can precisely position each part, with the positioning accuracy up to 10cm. The intelligent assembly workshop assembly process control algorithm based on digital twin is shown in figure 3. In the assembly workshop, the parts need to be transported from each processing station to the assembly station for assembly, therefore, using UWB real-time positioning of each parts and assembly station can determine assembly process through the various parts of moving track and the time which arrived at assembly station [23]. The assembly sequence is generated when the assembly part arrives at the assembly station but is not assembled, and the assembly sequence information is transmitted to the twin workshop through the Ethernet interface. In the twin workshop, the Markov method is used to predict the future assembly sequence according to the current assembly sequence, and the predicted results are transmitted to the assembly workshop control system. The system compares the predicted assembly sequence with the standard assembly process and feeds back the decision to the real assembly workshop. If the predicted assembly sequence is different from the standard assembly process, it will give an early warning to the real assembly workshop, reminding the assembly workers to stopping and adjusting the assembly operation and pay attention to the operation behavior in the next stage. In the process of product assembly, the twin workshop and the assembly workshop control system execute the above control process repeatedly until the entire product is completed with guaranteed quality.

![Figure 3. Intelligent assembly workshop assembly process control algorithm based on digital twin.](image)

The Manhattan distance algorithm originated from the distance calculation of the city block. It can easily calculate the distance between two points [24]. In this study, the Manhattan distance calculation ideal is introduced into the assembly quality calculation, which can effectively and accurately calculate whether the assembly quality in the current state meets the assembly quality requirements. In the process of assembly, a large number of screws, bolts, rivets and other connectors will be used to connect two or more parts. In this process, a large number of assembly quality data such as torque and tension will be
generated, which directly determine the strength and service life of the product. The assembly quality data should be limited to a certain range to ensure the assembly quality according to the diameter, material and structure of the parts [25]. Therefore, real-time monitoring of these quality data in the assembly process is of great significance for improving product quality and standardizing workers' assembly behavior [26]. Figure 4 illustrates the intelligent assembly workshop assembly quality control algorithm based on digital twin. Firstly, in the real assembly workshop, workers are equipped with intelligent tools such as Internet of things screwdriver and Internet of things wrench. During the assembly operation, these intelligent tools will collect quality data such as torque and tension in real time and transmit these quality data to the twin workshops through the Ethernet interface. In the twin workshop, the difference between the measured quality data and the average value of the standard quality data interval is calculated by using the Manhattan distance algorithm, and the difference data is transmitted to the assembly workshop control system. The control system compares the difference with half the length of the interval of the standard quality data and feeds the result back to the real assembly workshop. If the difference value is larger than half the length of the interval of the standard quality data, it indicates that the measured quality data is not within the interval of the standard quality data and does not meet the assembly quality requirements. At this time, the system will give an early warning to the real assembly workshop, reminding the assembly workers to carry out secondary assembly at the corresponding joint and pay attention to the operation specification of the next stage. The twin workshop monitors the assembly quality in real time during the assembly process, and executes the above quality control process repeatedly until the whole product assembly is completed.

Figure 4. Intelligent assembly workshop assembly quality control algorithm based on digital twin.

The intelligent assembly workshop based on digital twin adopts the two-layer control mode of "station -- equipment" to control the assembly process and assembly quality [27]. Figure 5 represents the mode of intelligent assembly workshop management and control based on digital twin. As an intelligent assembly workshop based on physical assembly workshop is built, the digital twin assembly workshop, assembly workshop twin data and assembly workshop control system can be used to realize closed-loop control of assembly process and assembly quality. The information interaction between the digital twin assembly workshop and the real assembly workshop can be realized through the four links of "perception
"-- analysis -- decision -- execution" in the intelligent assembly workshop [28], which promotes the intelligence of the assembly workshop of complex equipment and solves the problems of lagging assembly quality monitoring in the assembly process.

Figure 5. Intelligent assembly workshop management and control mode based on digital twin.

Assembly workshop control system is based on Microsoft t.net platform and B/S architecture, using cloud location Service as the center of the system. It includes AI monitoring platform, Internet of things platform, resource location software, assembly quality and process control software, network protocol server, etc. According to the load, the system is to increase or decrease the number of location servers and to prevent missing location and location server resources waste. The cluster equipment deployment method of industrial ring network is adopted to perceive and collect the information of electronic label position, equipment status, assembly progress data, assembly quality data, etc. The data is encapsulated by User Datagram Protocol (UDP) and ModBus Protocol and then sent to SQL SERVER database.

Firstly, the assembly quality control algorithm and assembly process control algorithm is developed at the station. According to the assembly process documents and assembly quality requirements, real assembly workshop collects the assembly process information and the assembly quality information such as force, torque and displacement generated during the assembly process. The twin workshop simulates and forecasts the collected information and transmits the results to the control system. The control system compares the simulation and prediction results with the assembly process documents and assembly quality requirements. When the assembly process specification or assembly quality requirements are not met, the control system gives an early warning and sends adjustment orders to the real assembly workshop to ensure that each step of assembly operation meets the assembly requirements.

Secondly, the light sensor monitoring label, current monitoring label and vibration monitoring label are used to sense and collect the operation state of the equipment, voltage, current, vibration and other information in the operation process, so as to provide data support for guaranteeing the assembly quality.

5. The practice of prototype control system of intelligent assembly workshop in a wing assembly workshop

The digitalization and intelligentization of assembly workshop provide effective ways to improve production capacity. In the traditional assembly production, the wing assembly workshop of an aircraft factory needs to assemble more than 1000 parts to produce the wing of an aircraft. The assembly process route is complex and changeable, and the visualization degree of assembly process is low, so it is difficult to control in time. Assembly quality is often checked only after components or even the whole aircraft wing assembly is completed, so assembly quality control lags behind and traceability is poor.
In order to solve the above problems, improve the assembly quality and efficiency, the intelligent and digital transformation of a certain type of wing assembly line was carried out, and the prototype control system of intelligent assembly workshop was developed. Through the digital twin technology, the assembly process and assembly quality are controlled in real time.

5.1. Assembly process control

There are strict assembly process documents in the aircraft wing assembly workshop. However, in the actual production process, due to limited production conditions, complex workshop environment, different worker proficiency and other factors, the assembly process is often not implemented in accordance with the assembly process documents, which result in wrong loading, missing loading and other problems, seriously affecting product quality and prolonging the production cycle. This prototype system tests the leading edge of typical components in the wing production process, monitors the assembly process in real time, and makes corresponding analysis and decision according to the actual situation. Figure 6 shows the configuration and composition of the leading edge assembly of the wing. According to the assembly process documents, the correct assembly process of leading edge assembly of the wing is: \{1,2, (3,4,5,6), 7,9,8,10\} or \{1,2, (3,4,5,6), 7,9,10,8\}. (3,4,5,6) is the skeleton assembly composed of the front rib 2, front rib 3, front rib 4 and actuating cylinder support, as a component for the leading edge assembly of the wing. In order to facilitate the assembly and ensure the assembly accuracy, the front rib 1 and the front rib 5 are processed with round holes at the connection of the rectifying steel plate and are processed with a straight slot at the connection of the actuating cylinder. The front rib 6 has a 5mm process margin at the connection end of the actuating cylinder.

![Figure 6. Leading edge assembly of the wing.](image)

During the actual assembly process, the prototype system can precisely position each part, with the positioning accuracy up to 10cm. During the wing assembly process, parts need to be shipped to the assembly frame and the wing assembly is completed on the assembly frame. Therefore, I can judge the assembly process according to the trajectory of the parts moving to the assembly frame and the time they arrive at the assembly frame. The assembly quality and process control software includes Markov method. Markov method is used to predict the future assembly process according to the current assembly process. In order to further illustrate the role of Markov method in the control of assembly process, the assembly state when the front rib 1 is assembled and the skeleton assembly have been transported to the assembly station and not assembled is taken as an example to illustrate. At this time, the assembly sequence is \{1,2, (3,4,5,6)\}. Assuming that in the future assembly process, the assembly sequence state changes with a certain probability and the change does not change with time, the state transition matrix of the model can be obtained:

\[
P = \begin{bmatrix}
    E_{i1} & E_{i2} \\
    E_{i3} & E_{i4}
\end{bmatrix} = \begin{bmatrix}
    P_{11} & P_{12} \\
    P_{13} & P_{14}
\end{bmatrix}
\]  

(1)
In the above state transition matrix formula, $E_{11}$ is the frequency $P_{11}$ of the current assembly sequence $\{1, 2, (3, 4, 5, 6)\}$ changing to $\{1, 2, (3, 4, 5, 6), 7\}$ divided by the frequency $P_1$ of the assembly sequence $\{1, 2, (3, 4, 5, 6)\}$. The solution of Markov method under steady state condition is used as the prediction state of future assembly sequence. Therefore, the following formula can be obtained by using Markov steady-state probability solution method:

$$E_i' = E_i \times \begin{bmatrix} E_{11} & E_{12} \\ E_{13} & E_{14} \end{bmatrix}$$

$$E_{11} + E_{12} + E_{13} + E_{14} = 1$$

According to formula (1), (2) and (3), the prediction result of assembly sequence under steady state condition can be obtained. The assembly sequence results predicted by Markov method is listed in Table 1.

| Assembly sequence state change | Probability |
|-------------------------------|-------------|
| $\{1, 2, (3, 4, 5, 6)\} \rightarrow \{1, 2, (3, 4, 5, 6), 7\}$ | 45%         |
| $\{1, 2, (3, 4, 5, 6)\} \rightarrow \{1, 2, (3, 4, 5, 6), 8\}$ | 20%         |
| $\{1, 2, (3, 4, 5, 6)\} \rightarrow \{1, 2, (3, 4, 5, 6), 9\}$ | 25%         |
| $\{1, 2, (3, 4, 5, 6)\} \rightarrow \{1, 2, (3, 4, 5, 6), 10\}$ | 10%         |

In this group of assembly sequence changes, $\{1, 2, (3, 4, 5, 6)\} \rightarrow \{1, 2, (3, 4, 5, 6), 7\}$ is the correct direction of the assembly process, consistent with the standard assembly process. Therefore, at this time, the assembly can be continued, and the assembly operation is performed on the skeleton assembly that are transported to the assembly frame but not assembled. Otherwise, if the assembly of skeleton assembly is completed, the workers mistakenly believe that the next step is to install the front rib 6 and transport the front rib 6 to the assembly frame. At this time, the assembly sequence generated is $\{1, 2, (3, 4, 5, 6), 8\}$. According to formula (1),(2) and (3), the probability that the predicted assembly sequence is consistent with the standard assembly process is 0, indicating that $\{1, 2, (3, 4, 5, 6), 8\}$ is the wrong direction of the assembly process. At this time, the assembly workshop control system timely sends an early warning of stopping and adjusting assembly operation to the real assembly workshop to avoid rework caused by wrong loading and missing loading, thus assembly quality and efficiency are improved.

5.2. Assembly quality control

Because the wing assembly process, workshop environment are complex and assembly operations need to be completed on the assembly frame with complex structure, manual assembly is still adopted for wing assembly. In the process of assembly operation, due to the different quality and experience of workers, fatigue and other factors, the torque, force and displacement exerted on parts during the process of assembly operation may fail to meet the assembly quality requirements, thus affecting the strength, life and product quality of the wings. By equipping assembly workers with intelligent tools such as Internet of things screwdrivers and Internet of things wrenches, quality data such as torque and force generated during assembly operations can be collected in real time.

In order to further illustrate the function of Manhattan distance algorithm on assembly quality control, the front rib 6 is connected with actuating cylinder and rectifying steel plate as an example. When the front rib 6 is assembled into the actuating cylinder and the rectifying steel plate, four M12 ordinary bolts should be installed and the torque should be controlled within the range of 58~78N*m. This specification torque range is denoted as (a,b). Four sets of torque data were collected when workers used Internet of things wrenches for assembly operations, and these four sets of torque data came from different batches of leading edge assembly of the wing assembly. These data are numberded according to the sequence of collection time. As shown in table 2, formula (4),(5) and (6) are used to calculate the absolute quality deviation, that is, the difference between the quality data collected in real time and the average value of
the interval of the standard quality data, and calculate the relative quality deviation, that is, the ratio of the absolute quality deviation which is greater than half of the interval length to the average value of the interval of the standard quality data. Manhattan distance formula and relative quality deviation calculation formula are as follows:

\[ \Delta = \text{dist}(X, Y) = |x_i - x_0| \tag{4} \]

\[ \delta = \frac{\Delta_m}{x_0} \tag{5} \]

\[ \{\Delta_m \in \Delta | \Delta_m > \frac{a + b}{2}\} \tag{6} \]

In formula (4),(5) and (6), \(x_i\) is the measured quality data, \(x_0\) is the average value of the interval of the standard quality data, \(\Delta\) represents the absolute quality deviation, \(\delta\) represents the relative quality deviation, \(\Delta_m\) represents the absolute quality deviation greater than half of the interval length, \(a\) represents the upper limits of the interval of the standard quality data, \(b\) represents the lower limits of the interval of the standard quality data. The absolute and relative quality deviation of measured quality data are summarized in Table 2.

Table 2. Absolute and relative quality deviation of measured quality data.

| Serial number | Measured torque data (N*m) | The interval of the standard quality data (N*m) | Absolute quality deviation (N*m) | relative quality deviation |
|---------------|-----------------------------|-----------------------------------------------|---------------------------------|---------------------------|
| 1             | 69.43                       | (58, 78)                                     | 1.43                           |                           |
| 2             | 65.71                       | (58, 78)                                     | 2.29                           |                           |
| 3             | 51.65                       | (58, 78)                                     | 16.35                          | 24.0%                     |
| 4             | 70.94                       | (58, 78)                                     | 2.94                           |                           |
| 5             | 77.31                       | (58, 78)                                     | 9.31                           |                           |
| 6             | 74.56                       | (58, 78)                                     | 6.56                           |                           |
| 7             | 56.35                       | (58, 78)                                     | 11.65                          | 17.1%                     |
| 8             | 68.61                       | (58, 78)                                     | 0.61                           |                           |
| 9             | 80.52                       | (58, 78)                                     | 12.52                          | 18.4%                     |
| 10            | 49.47                       | (58, 78)                                     | 18.53                          | 27.25%                    |
| 11            | 58.79                       | (58, 78)                                     | 9.21                           |                           |
| 12            | 60.43                       | (58, 78)                                     | 7.57                           |                           |
| 13            | 75.30                       | (58, 78)                                     | 7.3                            |                           |
| 14            | 68.44                       | (58, 78)                                     | 0.44                           |                           |
| 15            | 67.36                       | (58, 78)                                     | 0.64                           |                           |
| 16            | 69.58                       | (58, 78)                                     | 1.58                           |                           |

According to the diameter, material and structure of the connecting parts, the torque when connecting the front rib 6 with actuating cylinder and rectifying steel plate should be controlled in the range of 58~78N*m. At this time, the half of the interval length of the standard quality data is 10N*m. The absolute quality deviation calculated from the collection points with serial numbers of 3, 7, 9 and 10 is greater than 10N*m, which indicates that the measured quality data at the collection points are not within the standard quality data range and do not meet the assembly quality requirements. At this time, the system will send an early warning signal to the real assembly workshop to remind the workers to carry out secondary assembly at the corresponding joint. Relative quality deviation is used to measure the standard degree of the assembly operation. For example, the relative quality deviation of the collection point with the serial number of 10 is up to 27.25%, which indicates that the torque of the assembly operation is seriously deficient and the assembly quality is poor. Based on this, the workers should pay attention to the operation specification of the next stage. Through the visual interface, the prototype system can control the assembly quality in real time, which has benefits to solve the problem of lagging
quality inspection in the production process, improving the assembly quality and standardizing the operation of workers.

6. Conclusion
In view of the complex assembly process and low quality in the production process of aircraft wing assembly workshop, the research on the quality control mode of intelligent assembly workshop based on digital twin was carried out. This mode had realized the collection of resource location information, assembly process information and assembly quality information. On this basis, Markov method and Manhattan distance algorithm were used to realize assembly process and quality control in assembly workshop. The following three conclusions can be drawn through the example verification. Firstly, the Markov method can be used to predict the future assembly sequence according to the current assembly sequence, and the predicted assembly sequence can be compared with the standard assembly sequence, so as to verify the feasibility of the current assembly state and avoid the rework caused by wrong assembly and missing assembly. Secondly, the Manhattan distance algorithm can be used to calculate the absolute quality deviation. By comparing the absolute quality deviation with half the length of the interval of the standard quality data, it can verify whether the current assembly quality meets the assembly quality requirements, and monitor and control the assembly quality in real time. Finally, the feasibility of the control mode of the intelligent assembly workshop based on digital twins is verified. Through the interaction and cooperation of the real assembly workshop, the twin assembly workshop and the assembly workshop control system, the real-time and dynamic control of the assembly workshop can be achieved, which provides a new method for the control of the complex assembly workshop. The control mode application in the assembly workshop can realize resource positioning, assembly process control, assembly quality control, effectively improving the assembly process and quality control ability in the complex assembly workshop. However, at present, assembly quality and process control in the assembly workshop of complex equipment products such as aircraft wings are still in the exploration stage. As a new mode of control, the research on the quality control mode of intelligent assembly workshop based on digital twin needs further research and verification.

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