Research on Intelligent Assembly Modes of Aerospace Products Based on Digital Twin

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Abstract. Based on the multi-varieties and scalable batch production mixed line assembly of aerospace products, this paper proposes the technical approach and system architecture of an intelligent assembly integration platform which is composed of hardware layer, software layer and application layer from bottom up, so as to construct an intelligent assembly integration application platform based on the digital twin. Hardware layer is composed of the equipment and communication, software layer mainly includes the database and functional modules, and application layer is constructed based on a digital twin model, realizing visual monitoring of the assembly process. This paper establishes an intelligent monitoring mode based on digital twin and an intelligent control mode based on two-layer optimization. At the workshop layer, a digital twin mode of entities is constructed so as to form a plan optimization information, logistics optimization information and quality optimization information, and post control optimized execution information is sent back to the workshop operational layer. At the assemble line layer, real-time information is acquired, equipment monitoring is realized, and optimized information is sent back to the workshop operational layer, achieving control and optimization of assembly lines. This paper reshapes processes under this intelligent assembly mode; and verify its application in aerospace product assembly.

Keywords: digital twin; assembly mode; aerospace

1. Introduction
Aerospace products are characterized by multi-variety, scalable batch production, multi-model collinear production, complex assembly and control difficulties. In recent years, China has made great efforts to promote the deep integration of new information technology and artificial intelligence technology with the manufacturing industry, as well as achieve the transformation and upgrading of the manufacturing industry through intelligent manufacturing. In view of this, a study on the intelligent assembly mode of aerospace products is conducted.

Digital twin is one of the important approaches to realize intelligent manufacturing, which creates a physical entity through a digital virtual model, simulates the behaviors of the physical entity in real life, carry out total factor and full service data driven virtual simulation on the product itself, the manufacturing process and the manufacturing resources, so as to achieve the targets of improving system capacity, efficiency and quality \cite{1} \cite{2} which can be applied to all stages of the product life cycle from design \cite{3}, manufacturing \cite{4} to after-sales service \cite{5}.

2. Construction of the intelligent assembly integration platform
2.1. Technical approach
Taking into consideration the current situation of multi-varieties and scalable batch production mixed line assembly of aerospace products and combining with product features and assembly requirements, the technical approaches are determined as follows:

(1) Adopt production line simulation and evaluation optimization technology to realize on-site assembly process planning and optimization, increase utilization rate of assembly site resources, and meet production needs of multi-varieties and cycled assemblies;

(2) Adopt an automatic material distribution system to realize state sensing and real-time control of the material transfer equipment, so as to meet the requirements of timely and accurate material distribution;

(3) Introduce auxiliary assembly equipment such as cabin docking, establish automatic assembly stations in place of manual operation, and improve assembly efficiency and quality conformance;

(4) Adopt workflow technology to realize refined control of process-based product scalable batch production mixed line assembly process, so as to generate complete, accurate and real-time product resumes;

(5) Adopt digital online quality inspection technology to realize online monitoring and statistical analysis of key quality features, so as to meet the requirements of follow-up quality traceability and continuous process improvement.

2.2. System architecture
With regards to the determination of technical approaches, due to the problems such as low production efficiency, no guarantee of quality conformance, difficulties in effective quality control and low level of automation and flexibility, this paper proposes system architecture of an intelligent assembly integration platform based on digital twin, as shown in Figure 1, which is composed of hardware layer, software layer and application layer from bottom up.

Hardware layer: this layer is composed of the equipment layer and communication layer. Equipment refers to the flexible assembly unit composed of assembly stations, data acquisition equipment and intelligent logistics equipment; and communication is mainly aimed at the multi-source and heterogeneous data generated in the workshop, and data transmission is realized by means of an industrial control network.

Software layer: this layer mainly includes the database layer and functional layer. The database layer establishes a data repository that supports the building of workshop 3D models, dynamic assembly scheduling, material management, equipment integration and assembly process control in the assembly workshop; and the functional layer mainly includes four main functional modules of the platform: assembly process planning and optimization, integrated assembly process management and automatic material distribution control in the assembly process, and adaptive flexible assembly.

Application layer: this layer is constructed based on a digital twin model, realizing visual monitoring of the assembly process; management and control of plans, processes, logistics and quality are achieved via the calculation and analysis of the data-driven digital twin model.

3. Control and optimization of the intelligent monitoring and decision-making mode based on digital twin

3.1. Visual monitoring mode based on digital twin
Through the construction of a digital twin model, the visual monitoring of the assembly lines, assembly station layouts and logistics operation equipment is realized. The assembly process data, material data, scheduling data and quality data of the assembly line are obtained in real time through virtual and real mapping of the assembly workshop and the digital twin model, and the effective information is extracted with data mining technology to realize the visual monitoring of the assembly process information.
Firstly, according to the overall situation of the workshop, making use of real-life production line resources such as workshop resources, station resources, equipment resource etc. as well as real-life logistics resources such as material handling equipment resources etc., and applying a two-dimensional modeling approach, a production line model of the workshop is established, realizing two-dimensional dynamic monitoring of the assembly workshop and workshop data analysis based on data sensing.

On this basis, a 3D modeling approach is used to establish the digital twin of the automatic material distribution process in the assembly workshop, so as to realize the dynamic planning simulation of logistics tasks in the assembly workshop and the real-time control of the intelligent decision-making of distribution behaviors.

![System architecture of the intelligent assembly integration application platform](image)

**Figure 1.** System architecture of the intelligent assembly integration application platform

### 3.2. Analysis, control and decision-making mode based on digital twin

The optimal control at the workshop level is shown in Figure 2. A digital twin mode of entities corresponding to the assembly site is constructed and data mining is carried out, so as to form a plan optimization information, logistics information, quality optimization information, etc., which are applied to the planning control module, logistics control module and quality control module of the intelligent product assembly integration management platform, and post-control optimized execution
information is sent back to the workshop operational layer, realizing workshop level control and optimization.

Figure 2. Logic diagram of workshop level optimization and control

The control and optimization of the production line are shown in Figure 3. Real-time production site information such as assembly site tasks, materials, equipment, etc. is acquired real time, and based on fuzzy reasoning rules, find the matching static model of the production system in the object database. According to temporal relations, restricted relations and mapping relations, construct a dynamic model of the assembly workshop, and apply real-time data to drive such dynamic model for simulation, so as to realize equipment monitoring, equipment troubleshooting and logistics path optimization, inventory optimization, etc., and to send optimized information back to the workshop operational layer, achieving control and optimization of assembly lines.

Figure 3. Logic diagram of optimization and control at production line level
4. Application verification

On the basis of the intelligent assembly integration application platform, the application verification of assembly mode is carried out and the new process is reconstructed, as shown in the Figure 4:

![Figure 4. Business processes](image)

After the Design Department sends the 3D model of the product to the PDM system, the preliminary assembly process planning, 3D process making and approval are completed according to the model. The PDM system sends the product BOM information to the ERP system.

The assembly process planning, simulation and optimization software receive 3D technology, complete assembly process planning, simulation analysis and optimization. Station layout, station task and logistics plans are confirmed.

The ERP system releases production orders. Dispatchers and operators prepare for production according to production tasks. The assembly process integration management and control software system receives the production orders and assembly process planning scheme.

Materials are distributed from the workshop secondary warehouse to the assembly site according to the order information and kept at the corresponding storage site.

Assembly MES system sends production tasks and other relevant information to the designated assembly unit, and issues material transport orders to the logistics management, distribution and control system.

The logistics management, distribution and control system receives the material transfer order and directs the material transport equipment to transfer the specified materials to the designated assembly unit, conducts real-time sensing and control of the transfer equipment, and track the materials.

The assembly unit receives the materials and confirms to start work. The assembly MES acquires and monitors quality data in real time, manages and controls quality issues, collects and statistically analyzes quality data, and establishes quality data packets.

After the assembly units completes its tasks, it reports to the MES system and submits production report data to the ERP system through data integration.

5. Conclusion

In this paper, an intelligent assembly integration application platform was constructed for the scalable batch production mixed line assembly of aerospace products, and an intelligent monitoring mode based on digital twin and an intelligent control mode based on two-level optimization were proposed. Moreover, application verification was conducted in the assembly of aerospace products, which promoted and led the development of military intelligent manufacturing technology.
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References
[1] ZHUANG Cunbo, LIU Jianhua, XIONG Hui, et al. Connotation, architecture and trends of product digital twin[J]. Computer Integrated Manufacturing Systems, 2017, 23(4):753-768
[2] Tao Fei, Liu Weiran, Zhang Meng, etc., Digital twin five dimensional model and ten fields of application. Computer Integrated Manufacturing System, 2019, 25(1): 1-18
[3] TAO Fei, SUI F, LIU A, et al. Digital twin-driven product design framework[J]. International Journal of Production Research, 2018, DOI:10.1080/00207543.2018.1443229
[4] TAO F, ZHANG M. Digital twin workshop-floor: a new workshop-floor paradigm towards smart manufacturing[J]. IEEE Access, 2017, 5:20418-20427.
[5] BIELEFEDT B, HOCHHALTER J, HARTL D. Computationally efficient analysis of SMA sensory particles embedded in complex aerostructures using a substructure approach[C]//Proceedings of ASME 2015 Conference on Smart Materials, Adaptive Structures and Intelligent Systems, 2015: V001T02A007.