Multidimensional Data Management System for Spacecraft AIT Process Based on Product Structure

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Abstract. In order to solve the problems such as poor integration and application of the data in spacecraft AIT process, this manuscript analyzes the evolution of AIT process data in three dimensions: product structure, time period and development stage from the aspects of data model construction and data integration. We built a multidimensional data model and developed a multidimensional data management system based on product structure. This system takes the product structure as the core, organizes the AIT process data, defines the correlation relationship between different systems and different dimensions, realizes the structured integration of the whole data of AIT process, and generates the AIT process packet.

1. Introduction
The spacecraft, represented by rockets, satellites and spacecraft, is characterized by variable demand, complex product composition, long technical process, numerous test verification and lengthy management mode [1]. Its development stage generally includes the scheme-the first sample-the positive sample. In each stage, it will produce a large number of different dimensions of technical and management data. In the process of spacecraft AIT (Assembly Integration and Test), there are process documents, execution records, inspection results, test data, multimedia records, planning data, auxiliary resource data, etc., which continue to accumulate, transmit and eventually file with the product development process, forming the spacecraft AIT process data packet.

These data are important for the continuous improvement of AIT technical processes, the promotion of product quality improvement, and the improvement of the level of management refinement, but at this stage, these data are not well collected, collated, analyzed and utilized, the main reasons are as follows:
1) Discrete manual assembly mainly, product status is changeable
   Because the spacecraft is in a small production state, the technical documents change frequently due to the change of demand, which results in the increase of repetitive work in the assembly process, resulting in frequent interaction between the process design and the data implemented in the field, and resulting in a large number of unconventional process data in the middle state [2].
2) Long product development cycle and unfavorable data storage method
   Spacecraft development is often up to several years, and there are often countercurrent operations in the development process [3], so the data recorded in the existing information system is mostly in accordance with the workflow timing storage. This only meets the need for data logging in the task
implementation process, but it has not yet implemented the associated storage with the product feature information.

3) Multiple systems run independently, and there are information silos

At present, the overall design and process design data have realized the application of Teamcenter, Windchill and other PDM (Product Data Management) systems based on structured data [4], but for professional test and test data, it is still managed through unstructured AVIDM (Aerospace Vehicles Integrated Design and Manufacturing) system. If multiple systems run independently at the same time, there will be an information silos phenomenon. This is not conducive to the use of AIT process data as a whole unified development.

4) Insufficient analysis and mining of data and low efficiency of data query

The data recording and storage functions of the existing business systems only meet the needs of their own business. There is not enough correlation between a large amount of execution record data and data such as product status statistics. It is unable to meet the needs of fast retrieval such as fast query and quality review of product-object data and is difficult to carry out longitudinal analysis and comparison of data within the model and horizontal analysis between models.

For the first and second types of problems, the usual solution for the management of AIT process data, both domestic and foreign, is that the business system runs independently and the data between systems is processed in an integrated manner. For example, integrating the MES (Manufacturing Execution System) used in the field with the CAPP system through the PDM system, or directly increase the information management function of process data on the MES system to realize dynamic feedback and sharing between multi-system data [5].

In the early stage, the integration of CAPP, MES and AVIDM systems based on unified product structure was realized in spacecraft assembly [6]. However, this form of data integration only uses the data interface mode of data push or read. When the process state changes, the countercurrent operation or the sequence hopping operation occurs, it causes the data confusion, and cannot meet the packet integrity, the consistency and the correctness request. Therefore, the consistency requirements of the three levels of process baseline, design baseline and assembly implementation data are put forward to ensure the linkage and integrity of process data in the event of change in process state [7].

For the third and fourth types of problems, the main solution is to build a data warehouse, integrate different systems, different forms and different structures of data to reconstruct based on data ETL (Extract Transform Load) technology. It also supports structured or specialized query, analysis reports, and decision making, so that discrete data can form interconnected multi-dimensional structured data models. The multidimensional structured data model is also called data cube. Its data is determined by the dimension and the actual content. Each dimension has a data table, which can express the relationship between data and dimensions, thus enabling multi-dimensional data query, statistics and analysis [8].

In the data integration process, it is generally integrated by using ESB (Enterprise Service Bus), combined with middleware, XML, Web services and other technologies to form a topology between multiple systems making all systems can be inserted into the ESB as a unit for integration and unified scheduling [9], so as to solve the problem of interface differences, data heterogeneity and late data synchronization between multiple systems [10].

By constructing the multidimensional data model with the actual process data of the product as the core, this manuscript integrates and reconstructs the data between various data systems from three dimensions of product structure, time period and stage model, and forms a complete structured data management system. And we hope to develop data standards, improve data quality, lay a foundation for mining data value and ultimately improve the level of design specialization and assembly implementation consistency based on data model.

2. Data content and model construction

At present, AIT process data mainly includes final assembly implementation data, professional test data, large-scale test data, management data and resource data (as shown in Fig.1), which are actual operation, inspection and test data generated during the AIT development process.
The four categories of data shown in the figure are quite complex, and many data do not have interrelated logical relationships. Therefore, it is necessary to change the existing way of data storage driven by the work business process, reorganize the data structure of each business, and transform the "process-based" sequential storage method into a "product-based" data storage method using the "product structure" as the index. As a result, by constructing the multidimensional data model, hundreds of kinds of data are filled into the data structure similar to the "Rubik's Cube", which mainly includes three dimensions of product structure, time period and development stage (as shown in Fig. 2).
1) In terms of product structure dimensions, spacecraft products typically include four levels: the whole spacecraft-module-module plate-equipment (cable/direct -parts/pipeline). The product structure changes from fragmented single units and components to final product and structural data through continuous assembly activities. Professional test data, as a specific product attribute, is associated with the corresponding product.

2) From the time cycle dimension, the AIT process has gone through four stages: process design-plan scheduling-operation execution-result feedback, and process data is cyclically evolved into time-series data flow in these four phases. When the state changes and the process file needs to be modified, the process data enters another time-series data flow through documents such as the on-site problem handling list. At the same time, in each development phase, there may be several similar data streams due to technical state adjustments, and different data streams reflect the state of the product at different times.

3) From the stage model dimension, the model will go through the scheme-the first sample-the positive sample stage, some complex models even have the appearance stage, and some batch equipment model has the scheme-the first sample-sample-stereotype development stage. Different models of batch models or common platform models, such as XX-1 and XX-2, are also compared in this dimension.

3. Overall structure of the system
Based on the multidimensional data model and data management system technology, this manuscript forms a real digital prototype with clear hierarchy and data correlation through structured storage, and build a data system which takes the spacecraft product structure as the catalogue index and the field production state (Including signing data, test data, photos, etc.) as input. This data system can truly react to the actual state of any product in the product structure under any time node.

The AIT process multidimensional data management system mainly includes three systematic modules of product structure module, data transmission module, data reconstruction and association module, as well as two functional modules of real digital prototype module and data application module. The system function and composition is shown in Figure 3.
The product structure module is used to establish a complete "product structure skeleton". The data transmission module collects and organizes the existing business information system data. The data reconstruction and association module reconstructs the data, associates with the "product structure skeleton", and then completes the filling of the data content. Real digital prototype module, based on data drive, displays product status information in the form of tables or photos. The data application module mainly collects and analyzes the accumulated data to meet the requirements of state control, quality review, and data mining.

4. Detailed design of the system

1) Product Structure Building Module

The process prototype is based on the overall 3D model input and constructed according to four levels of the whole spacecraft-module-module plate-equipment (cable/direct parts/pipeline), then it forms the product structure. System overall architecture, final assembly design model, sub-system design model and related design documents are summarized into the process, and then the process prototype is generated after integration processing. The build process is shown in Figure 4, and the product structure is shown in Figure 5.
2) Data transmission module

There is a phenomenon in the AIT process that the same data is recorded in multiple places, and this "data redundancy" brings about a certain phenomenon of "data contradiction", which affects the traceability of the process. Therefore, the system must adhere to the principle of unified data source and do not produce any data. All the data of the system are transmitted from the existing data system or entered through files, etc., then the system becomes the only integration center of the data. Different transmission paths and interfaces are designed for different information systems. System integration can use Webservice, ETL extraction, intermediate table or intermediate file synchronization to ensure the integrity of the data transfer. The data management system itself transmits data only through other data systems, and the data outside the office network is imported into the corresponding information system.
through the physical media, and then transmitted through the data interface in the office network. The data integration relationship between systems is shown in Fig 6.

**Figure 6.** Data integration of systems

After summarizing the data of each heterogeneous system, the data quality directly affects the data value, including the integrity, consistency and standardization of the data. So the data needs to be cleaned during transmission, as shown in Fig 7. By setting standards and specifications for various types of data, and setting verification rules in the system, it can check and automatically correct the data, or give correction suggestions.

**Figure 7.** Process of data cleaning
3) Data reconstruction and association module

The data reconstruction and association module reconstruct the data based on the process so that it is associated with the "product structure skeleton", and then completes the filling of the data content. Its main process is shown in Fig 8.

![Figure 8. Process of data restructure and correlation](image)

Because the data in the system represented by the packet is integrated from each system, in order to ensure the integrity and accuracy of the AIT process data, baseline and version management of the data in the system is required. This ensures that the version of the data in each dimension of the system is consistent, and avoids query errors caused by data state differences.

The final assembly implementation and actual data feedback record the relatively complete assembly process data (status, data, signature record, etc.) using the process documentation as the carrier. Through the MES interface, the data backhaul realizes the feedback of the final assembly production information in the MES to the system, such as the equipment installation status and the thermal control implementation status.

Based on the multimedia data management requirements of product structure, multimedia records in the process of 3D process design need to be modified by TC system. The photographing requirements need to be defined in the process file and associated with the corresponding product to form a structured photo recording requirement, so that the MES system real state photo record can be transmitted back to the system.

Unstructured data processing extracts the process information in the data composition, then fills it into a structured product template, and manually supplements and iterates the missing information, so that the automated information reconstruction is gradually realized.

4) Real prototype module

The module implements an associative query for the status of a specific product, and can display information such as the working status and results of each operation of a specific product (such as equipment, plugs, etc.) under the entire AIT process, execution records, and corresponding multimedia records. It realizes the complete display of the technical state, and can drive the model increase and decrease in real time based on actual operation and inspection signature data of assembly execution system feedback, and implements the function of displaying “the real state of the spacecraft at a certain time” [11].

5) Data application module

The data application module is mainly used for statistics and summarization of the final assembly deviation data based on the template table, as well as custom query and data mining. The design of the database refers to big data software deployment and management tools such as Impala [12]. This enables structured AIT data to form data content that is easy to query and count, so that it is possible to achieve longitudinal contrast of the same model and horizontal contrast between different models. For example,
it is convenient to retrieve and query the installation status and final assembly data of similar devices of a batch of satellites on different models for lateral comparison; if a key component is disassembled and assembled multiple times, it can inquire about the execution record and on-site photo of each disassembly and assembly.

5. Conclusion
Starting from data model construction and data integration, this manuscript analyzes the evolution process of AIT process data in three dimensions: product structure, time period and development stage, constructs multidimensional data model, and develops multi-dimensional data management system based on product structure. This system takes the product structure as the core, reorganizes the AIT process data, defines the relationship between different systems and different dimensions of data, realizes the structural integration of the AIT process data, and generates the AIT process data package on this basis. In the follow-up, we will continue to study data mining and application, and provide strong support for improving the design level and improving the development process of AIT.

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