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Construction of MBD Model-Driven Quality Control Data Chain for Parts Machining Process

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Abstract. Aiming at the problems of inconsistent data sources and much manual intervention in the process of quality inspection planning, data acquisition and analysis of traditional parts machining, an MBD model-driven quality control data chain model for parts machining process is constructed. Firstly, through the analysis of the MBD model and the quality characteristics-oriented primary inspection planning, the automatic generation of the inspection task XML file for the inspection process is presented. Secondly, the automatic generation method of the MBD model-driven CNC program for the on-machine inspection of the CNC machine tool and the CMM inspection DMIS program is given. Then the automatic acquisition method of the on-machine measurement results of the CNC machine tool based on OPC UA and the CMM inspection results based on the secondary development of PC-DMIS are proposed, which realizes the automatic acquisition of quality data for process-oriented tasks, XML format packaging, and then realize the quality analysis and monitoring of the processing based on quality data. Finally, the MBD model-driven inspection planning and quality data acquisition system (MD-IPQDA) is developed, which significantly improves the accuracy and transmission efficiency of quality data verified by application.

Keywords. MBD model, inspection planning, automatic data acquisition, OPC UA, data chain

1. Introduction

In the process of transformation from informatization to digitalization of manufacturing enterprises, enterprises have carried out the informatization of management and the digitization and intelligence of manufacturing process. Because of its advanced new thinking of design-manufacturing-Inspection-utilization integration, MBD technology has been widely concerned and implemented by enterprises [1-2]. Although MBD technology provides a technical basis for realizing automatic delivery and automatic identification of product design models to manufacturing and inspection stages. However, how to integrate this advanced technology with the quality control business in the manufacturing process, connect to the data link of the quality control in the

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manufacturing process, and realize the digitization and automation of quality control has become an urgent problem to be solved.

The control of parts machining quality originates from design specifications and process planning. After inspection planning, quality inspection (quality data acquisition), quality data statistical analysis and problem discovery, the closed-loop process of product quality management is realized. At present, in the process of product quality control of manufacturing enterprises, from the definition of product quality requirements and the proposal of inspection requirements, to the execution of inspection work and the acquisition of quality data, to the data analysis and prediction of process quality, the information flow and the process flow is separated in the entire process. It mainly relies on human intelligence to connect this discontinuity, resulting in problems such as ambiguity in understanding, delays and errors in execution, and heavy reliance on human experience, making product quality control and management work cannot meet the needs of continuous improvement of product quality and proactive prevention of quality problems in the digital manufacturing process. Self-inspection, mutual inspection and special inspection are the traditional quality control modes in the production process, which are based on the human-centered quality control. With the development of MBD technology, the popularization and application of automation and intelligent equipment such as CNC machine tools with on-machine measurement instrument and CMM equipment, and the emergence of industrial communication standards such as OPC UA, these are all important factors for providing basic conditions for getting through the data link of inspection planning and quality inspection, and for realizing the digitization and automation of quality control in the manufacturing process.

In order to connect the data link of design requirements→inspection planning→quality data acquisition→quality statistical analysis, and improve the efficiency and standardization level of quality control during parts machining, scholars from native and abroad have carried out a lot of research on this. Du Fuzhou [3] et al. proposed a method to form automatic generation and execution of the first article inspection based on the MBD model based on inspection standard of aviation products, but the research content did not involve inspection planning, data acquisition and statistical analysis; Duan Guijiang [4], Shen Xinru [5] and other researches mainly focus on the realization of measurement point planning and path planning technology based on MBD, without considering the problems of quality data acquisition and quality analysis; Yang Hao [6] et al. have studied the aircraft manufacturing quality control and monitoring way based on MBD, but only the assumption is given, and the specific implementation scheme is not proposed; Rui Liu [7] et al. constructed the framework of integrated inspection system based on MBD model, and discussed the inspection planning of machine measurement and coordinate measuring machine (CMM) measurement, process quality monitoring based on inspection data, but the realization method of the complete data link is not mentioned. The American Digital Metrology Standards Association [8] (DMSC) released the Quality Information Framework 3.0 (QIF3.0) standard, which defines a set of integrated quality inspection information models applicable to the entire manufacturing process, and proposes a complete quality control closed-loop architecture as well as data dictionary and XML model file, providing valuable quality information model for MBD-based manufacturing process quality control.

This paper aims to connect the data link of parts machining quality inspection planning→quality data acquisition→quality statistical analysis. The integrated model of production process quality management driven by MBD model was constructed. The inspection planning method based on MBD model was proposed. The automatic generation approach for the inspection programs oriented to on-machine measurement and CMM were given. And the way of acquisition of on-machine measurement data based on OPC UA and CMM measurement result data based on PC-DMIS secondary development were addressed. Finally, the MBD model-driven inspection planning and quality data acquisition software system was developed, and the feasibility and effectiveness of the technical method are verified through engineering examples.

2. The Quality Control Model of the Machining Process Driven by MBD Model

The quality control model of the machining process driven by the MBD model is shown in figure 1. The process model involves three main software systems: CAPP (Computer Aided Process Planning), MES (Manufacturing Execution System) and MBD Model-Driven Inspection Planning and Quality Data Acquisition System (MD-IPQDA). Through the integration of the above three systems, the process realizes the definition of inspection requirements based on the MBD model, and to the inspection planning based on the MBD model, then to the automatic inspection of product quality characteristics, and finally to the automatic acquisition of product quality data and the automation of statistical analysis of product quality data.

It can be seen from figure 1 that the quality control of the production process driven by the MBD model is mainly divided into the following four steps:

(1) Inspection planning based on MBD model. In this step, the MBD model with PMI (Product Manufacturing Information) annotation information is imported from the CAPP system, and inspection information such as geometric dimensions and geometric tolerances of parts is obtained by identifying, extracting and analyzing the PMI annotation information; Inspection planning and post-processing generate on-machine measurement programs that are compatible with CNC systems (such as Siemens, FANUC, etc.); DMIS measurement programs are generated through inspection planning and post-processing oriented to CMM measurement. Associated with the measurement program also includes inspection task information such as the product name, product ID, process name, process ID, operation ID, quality characteristics to be inspected, nominal dimension of quality characteristics (QC), upper deviation and lower deviation of the QCs. The above inspection task information is uploaded to the MES system from the MD-IPQDA system in form of XML file together with the measurement program.

(2) Issue and execution of inspection tasks. The MES system imports the received inspection program and quality characteristic inspection information into the process task node of the corresponding product by parsing the XML file of inspection task. After the MES system plans and schedules the processing tasks, it sends the CNC program and the on-machine inspection program to the CNC machine of the corresponding station through the network, and it sends the CMM measurement program to the computer system connected to the CMM. Among them, the on-machine measurement is used to realize the self-inspection of the machining quality of the part process, and the CMM inspection is used to realize the special inspection of the machining quality of the part process.

(3) Automatic acquisition of quality data at the production site. After the CNC machine tool completes the process processing, it can directly run the on-machine measurement program to complete the inspection of quality characteristics. The OPC UA protocol is used to collect the inspection results in real-time by subscription, and the inspection results are packaged into XML format files and uploaded to the MES system; for parts that require CMM inspection, the inspection results of the quality characteristics are directly read through the secondary development of measurement software such as PC-DMIS, and the results are packaged into XML files and directly uploaded to the MES system. The MES system adjusts the production plan according to the inspection results.

(4) Process quality monitoring and analysis. According to the measured value information of the quality characteristics of the parts collected, the MES system realizes the statistical analysis of the processing quality data of the same type, multi-batch and multi-station parts, analyzes the processing ability of the processing process and provides feedback on the quality improvement points.

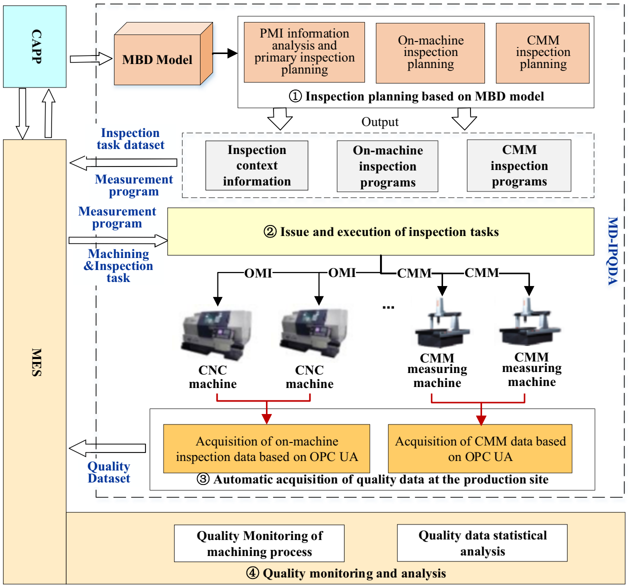


Figure 1. Machining process quality management driven by MBD model.

Through the above 4 steps, the quality control data chain of the part machining process can be automatically formed.

3. Inspection Planning Based on MBD Model

The CAPP system provides a 3D model of the part with PMI information, which contains most of the information required for inspection, such as part information, geometric feature information, geometric dimensions, geometric tolerances, and inspection requirements. The inspection planning based on the MBD model establishes the relationship between the geometric characteristics of the part and the quality characteristics to be inspected by analyzing the MBD model of the part, and realizes the extraction of annotation information and the structured processing for inspection tasks. On this basis, the primary inspection planning for quality characteristics is carried out, followed by measuring point planning and path planning for on-machine inspection and CMM inspection, and finally generating measurement programs and inspection context information XML files.

3.1. PMI Annotation Information Analysis and Primary Inspection Planning

The inspection-related information contained in the MBD model is shown in figure 2, which mainly includes inspection context information, geometric feature information, inspection annotation information and part of the inspection requirement information. Among them, the inspection context information includes part name and number information, product drawing number, process name and process information, etc.; geometric feature information is the geometric elements and features in the 3D model, such as "cylinder", "cone", "groove", "hole" and contour features such as "point", "line", "surface", etc., they are the carrier of PMI annotation and the basic constraint for measuring point planning; the inspection and annotation information is the PMI information attached to geometric features, including geometric tolerances , geometric dimensions, benchmarks, surface roughness, etc.; inspection requirements information includes technical requirements and inspection requirements.

Inspection information analysis is to obtain inspection context information, inspection-related geometric features, geometric dimensions, geometric tolerances, benchmarks and other inspection annotation information and inspection requirements related to the quality characteristics to be inspected through automatic extraction and interactive operations. This information is basic normative information for inspection planning and quality data acquisition.

The primary inspection planning is oriented to quality characteristics. It mainly determines the sequence of quality characteristic inspections, the inspection methods (on-machine inspection, CMM inspection and manual inspection), inspection equipment, and inspection times in the inspection process. The associated information composition of the inspection plan obtained after analysis and preliminary inspection plan is shown in figure 3.

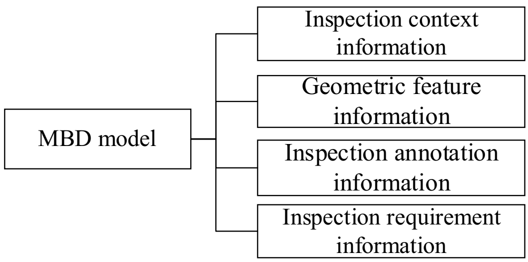


Figure 2. MBD model information related to the inspection.

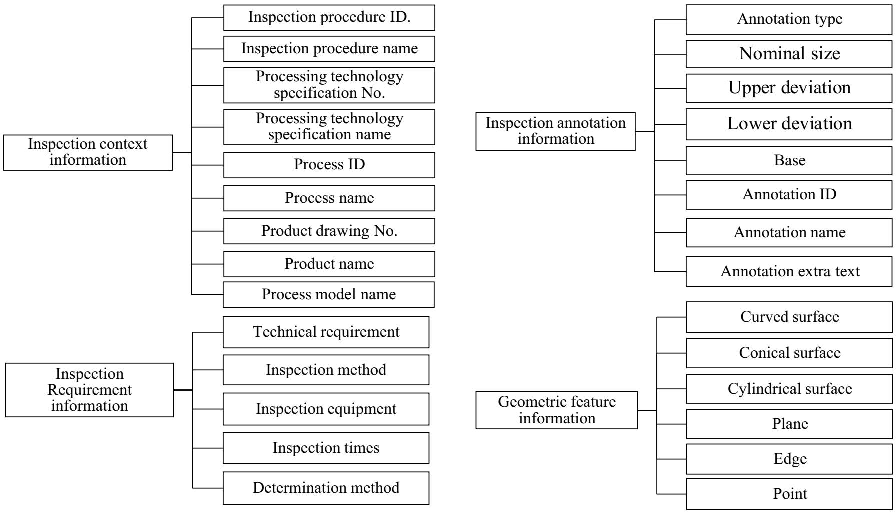


Figure 3. Associated information of inspection plan after parsing.

In figure 3, the inspection context information is the identification information of the inspection task, which ensures the uniqueness. Inspection annotation and inspection requirement information are normative information for inspection planning and inspection implementation. Inspection context information, inspection labeling information and inspection requirement information constitute complete process inspection task information. Geometric features are the internal basic information for on-machine inspection planning and CMM planning.

The inspection task information is encapsulated in the form of XML, and its XML Schema sample is shown in figure 4. Each inspection process includes multiple inspection procedures, namely OBJECT. The MODEL_INFO node contains all the inspection information for this inspection process.

```
<?xml version="1.0" encoding="utf-8"?>
<DATA>
    <FILE_TYPE VALUE="" />                         <!——File type
    <MODEL_INFO MODEL_NAME=" ">                    <!——Inspection process and model inspection information
        <PART_NAME></PART_NAME>                    <!——Part Name
        <PART_NO></PART_NO>                        <!——Part number
        <OPER_NAME></OPER_NAME>                    <!——Process name
        <OPER_NO></OPER_NO>                        <!——Process number
        <MODEL_ADDRESS></MODEL_ADDRESS>            <!——Model storage address

    <OBJECT GUIDSTR="2336" ClASSNAME="Inspection process" ClASSID="2336" OBJECTID="23360001">
        <ATTR VALUE="030jianyan-J2-1" DISPLAYVALUE="" ALIAS="Inspection item number" NAME="INSP_NO" />
        <ATTR VALUE="Diameter" DISPLAYVALUE="" ALIAS="Inspection item name" NAME="INSP_NAME" />
        <ATTR VALUE="On-machine measurement" DISPLAYVALUE="" ALIAS="Detection method" NAME="INSP_METHOD" />
        <ATTR VALUE="Interval" DISPLAYVALUE="" ALIAS="Judgment method" NAME="JUDGE_METHOD" />
        <ATTR VALUE="50.000" DISPLAYVALUE="" ALIAS="Theoretical value" NAME="I_VALUE" />
        <ATTR VALUE="+0.010" DISPLAYVALUE="" ALIAS="Upper deviation" NAME="IPLIMIT" />
        <ATTR VALUE="-0.010" DISPLAYVALUE="" ALIAS="Lower deviation" NAME="DOWNLIMIT" />
        <ATTR VALUE=" " DISPLAYVALUE="" ALIAS="Primary benchmark" NAME="PRI_DA" />
        <ATTR VALUE=" " DISPLAYVALUE="" ALIAS="Second benchmark" NAME="SE_DA" />
        <ATTR VALUE=" " DISPLAYVALUE="" ALIAS="Third benchmark" NAME="TH_DA" />
        <ATTR VALUE="Milling related tools" DISPLAYVALUE="" ALIAS="Inspection device name" NAME="INSP_TOOL" />
        <ATTR VALUE="1" DISPLAYVALUE="" ALIAS="Number of measurements" NAME="INSP_NUM" />
        <ATTR VALUE="" DISPLAYVALUE="" ALIAS="Measurement requirements" NAME="INSP_REQUIRE" />
    </OBJECT>
    </MODEL_INFO>
</DATA>
```

Figure 4. Example of inspection task XML.

3.2. On-machine Inspection Planning

On-machine inspection planning is a process for on-machine measurement of CNC machine tools to determine the best measuring points and measurement paths. Modern CNC machine tools (such as FANUC, Siemens, etc.) all provide on-machine measurement canned cycles (such as CYCLE977 measurement canned cycle of Siemens CNC system). The main task of on-machine inspection planning based on MBD model is to use the geometric features and inspection annotation information analyzed in Section 1.1, automatically calculate the parameters of the measurement canned cycle, and generate the measurement path. After path simulation, interference inspection, and post-processing, a CNC program that meets the requirements of the CNC system is generated. The process model of on-machine inspection planning is shown in figure 5. For the specific method of on-machine inspection planning, please refer to another paper of this research group, reference [9].

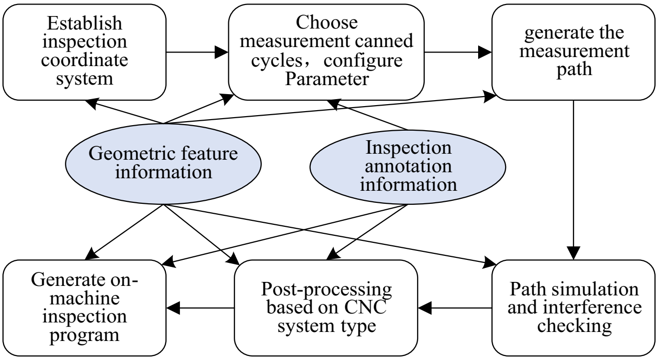


Figure 5. Model of on-machine inspection planning process.

3.3. CMM Inspection Planning

CMM inspection planning is the process of testing process quality characteristics for CMM measuring machines and determining the best measuring points and measurement paths. The main task of the CMM inspection planning based on the MBD model is to first establish the inspection coordinate system based on the geometric features and inspection annotation information parsed in Section 1.1, and then carry out the measurement point planning and path planning, and then carry out the path simulation and interference checking, and finally generate a DMIS-compliant measurement program. Among them, the measuring point planning is mainly realized on the geometric features to be detected, and the number and location of the measuring points are determined according to the marked geometric tolerance type and value range. Common distribution methods include fixed step length distribution, layered distribution, uniform random distribution, bus distribution, spiral distribution, etc.; path planning is to comprehensively consider the probe swing angle, motion obstacle avoidance and the shortest path to determine the sequence of measuring points in the measurement process. There are many studies on CMM inspection planning, which will not be repeated here.

The inspection task XML and measurement program generated by the inspection plan are uploaded to the MES system and combined with the part processing task, and then through the unified scheduling for production tasks, the processing and inspection tasks for the CNC machine tool processing station are formed, as well as the part inspection tasks for CMM measurement machine. The measurement program is sent to the corresponding CNC machine tools and CMM measurement machines through the DNC network system to perform related processing and inspection tasks.

4. Automatic Acquisition of Quality Data on Production Site

The automatic acquisition of quality data at the production site is the key to realizing the construction of quality control data chain. The traditional method is to remove the parts which are processed by the CNC machine tool, and then take size measurements and enter the results into the MES system. This not only wastes time, but also causes errors due to human reasons; in addition, the secondary clamping will also cause positioning errors, which will affect the subsequent processing quality.

4.1. Automatic Data Acquisition of On-machine Inspection

OPC UA (Open Platform Communications Unified Architecture) is a standard specification for data security exchange in the field of automation that supports cross-platform, and can be used for information exchange of field devices, control systems, etc. in the field of industrial processes. Siemens, FANUC, ABB and other industrial products all support the OPC UA standard.

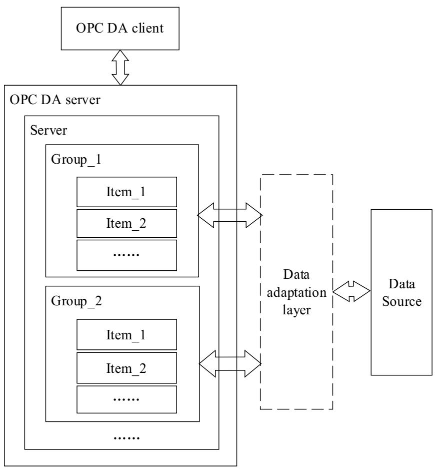


Figure 6. Structure of OPC DA server.

The following takes Siemens 840D sl CNC system as an example to introduce the on-machine inspection data acquisition method. OPC UA-based on-machine inspection data acquisition relies on the OPC Real-Time Data Access Specification (OPC DA). The architecture of the OPC DA server is shown in figure 6, which mainly includes three levels of objects, namely the server object (Server), the group object (Group) and the data item object (Item), and the three levels are from top to bottom. A Server object can contain multiple Group objects, and a Group object can also contain multiple Item objects. The OPC DA server is built into the Siemens 840D sl CNC system, and data acquisition can be achieved easily by using the OPC DA client. The basic unit of data acquisition is the Group object. Before data acquisition, the Item object to be collected needs to be added to the Group object, and the Group is operated as a whole.

In the Siemens CNC system, the results of on-machine inspection are usually stored in the R parameter. The client is added and selected by reading ItemID in the OPC server. As shown in table 1, the address space corresponding to the R parameter variable.

Table 1. R Variable address in Siemens 840D sl CNC system.

Variable address	Represented data
/Channel/Parameter/R[u1,0]	R0
/Channel/Parameter/R[u1,1]	R1
… …	... ...

Since the R parameter variable is too much, it will not be listed here. The method of obtaining the server address of the R parameter variables is as follows:

/Channel/Parameter/R [u<Area index>, <Row index>]

Among them, <Area index>=Channel number, <Row index> =R number. According to the corresponding R parameter variable server address, the variable value of the specified R parameter can be collected. For the results of the on-machine measurement, its R parameter variable is located in the SGUD variable area, and the corresponding address space is /NC/ _N_CH_GD1_ACX/ _OVR[<Row index>].

The collected on-machine measurement values are uploaded to the MES system in XML format to realize feedback on the completion of the inspection task.

4.2. Acquisition of CMM Measurement Data

The CMM completes the measurement of the geometric dimensions and geometric tolerances of the parts under the action of its supporting operation software system. Common CMM operating software includes PC-DMIS, PowerInspect, Metrolog, etc. These systems all provide secondary development functions to realize access to measurement results. The following takes PC-DIMS software as an example to introduce the automatic acquisition method of CMM measurement result data.

The measurement result data of the PC-DMIS system is stored in the DimensionCommand object, which has multiple member variables such as Nominal, Plus, Minus, and Measured, which respectively represent nominal size, upper deviation, lower deviation, and measured value. Use Microsoft Visual Basic to call the secondary development kit of Interop.pcdlrn.dll, initialize its parent class Application, PartPrograms, Commands, and then access the DimensionCommand member variable to get the inspection results. The results are uploaded to the MES system in XML format to realize feedback on the completion of inspection tasks.

5. Quality Monitoring and Analysis

The MES system receives the XML file of parts machining from on-machine inspection data and CMM inspection data uploaded by the MD-IPQDA system, and saves the measured value of the parts machining in the corresponding inspection task record by parsing the data files. For a single part, the deviation of the theoretical value and the measured value is calculated to determine whether the part process is qualified; for a batch processing process composed of multiple parts, the process quality is monitored by drawing a control chart. In this way, possible problems in the production process, process design and product design are found, and the purpose of improving product design and process design is achieved, realizing the closed loop of quality control.

Figure 7 shows the quality data assembly method for processing tasks in the MES system. Among them, the self-inspection data for part process processing comes from the on-machine inspection data set, the special inspection data comes from the CMM inspection data set, and the rest of the data comes from the inspection task data set.

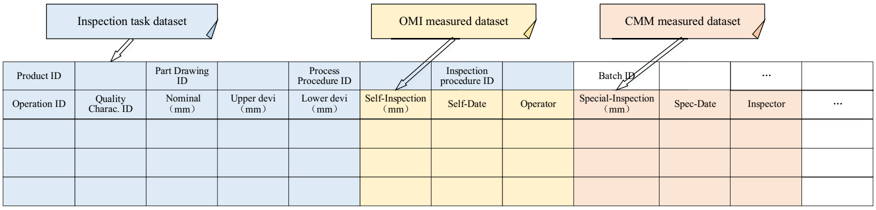
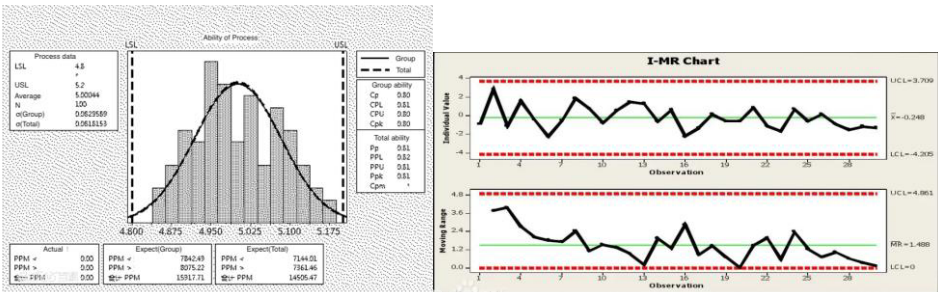


Figure 7. Quality data composition for process quality monitoring.

Figure 8 shows the process quality statistic chart and process quality control chart based on part processing quality data, which are used to monitor the quality of critical parts.



(a) Statistical analysis of quality data (b) Process quality monitoring

Figure 8. Quality data statistical analysis and monitoring.

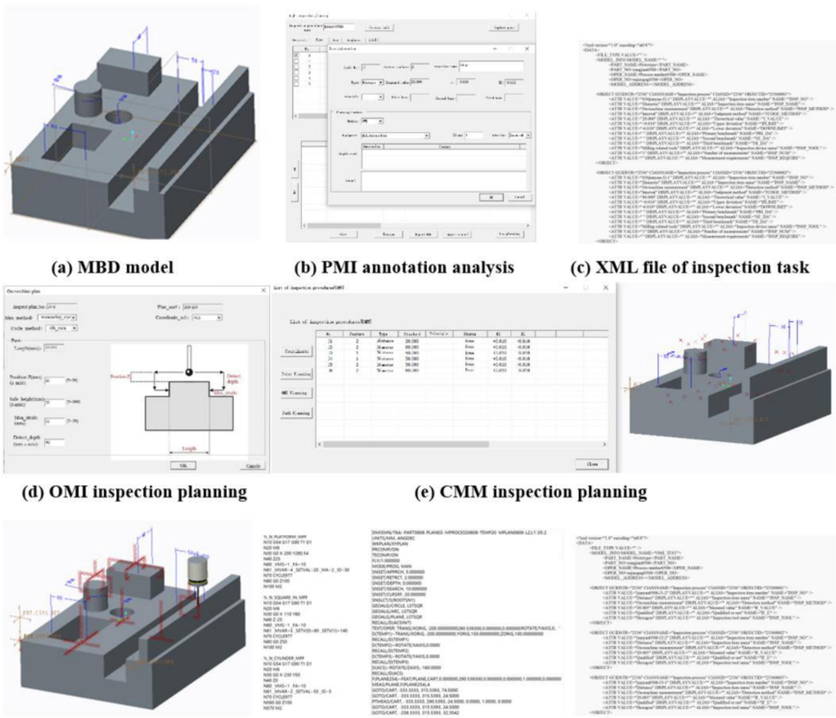
6. MD-IPQDA System Development and Application Evaluation

Based on the research of the above-mentioned technical methods, the MD-IPQDA system is designed and developed by using VisualC++. System functions include inspection planning based on MBD model, on-machine inspection data acquisition, CMM inspection data acquisition, data encapsulation and output, etc.

The inspection planning function based on the MBD model is designed and developed based on the secondary development package of ProToolkit. This function realizes importing the MBD process model from the CAPP system, and then identifies, extracts and parses the PMI annotation information, and then performs the primary planning for quality characteristics to form the XML file of the process inspection task.

Figure 9 shows the functional application effect of the MD-IPQDA system. Figure 9(a) is the sample MBD model, figure 9(b) is the PMI annotation analysis, figure 9(c) is the generated XML file of the inspection task, figure 9(d) is the on-machine inspection plan, figure 9(e) is the CMM inspection plan, figure 9(f) is the simulation of the planning path, figure 9(g) is the generated on-machine measurement program and CMM measurement program, and figure 9(h) is the XML file of the inspection result.

As the application shows, through the integration of MD-IPQDA system with CAPP and MES system, the connection of each session of the data link in the process of inspection planning based on MBD model, automatic issuance and execution of parts machining inspection tasks, automatic acquisition of inspection results, and monitoring and analysis of process quality are realized.



(a) MBD model (b) PMI annotation analysis (c) XML file of inspection task

(d) OMI inspection planning (e) CMM inspection planning

(f) Inspection path simulation (g) OMI and CMM inspection programs (h) XML file of inspection result

Figure 9. MD-IPQDA system function realization.

7. Conclusion

This paper proposes an MBD model-driven construction method for quality control data chain of parts machining process, which realizes the definition of quality characteristics to be inspected and takes MBD model as a single data source for the quality control requirements of parts machining process, the generation of inspection tasks, the generation of on-machine inspection programs and CMM inspection programs, the execution of inspection tasks, the acquisition of on-machine inspection results and CMM inspection results for processing tasks, the automatic acquisition and transmission of data in each link of process quality data integration and process quality monitoring and analysis, and verifies the effectiveness of the proposed method through system development and application. This method provides a data link construction method available for reference for realizing the fusion of information and physics in the process of parts machining in an intelligent manufacturing environment.

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