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MTConnect enabled interoperable monitoring system for finish machining assembly interfaces of large-scale components

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Abstract

Monitoring is an important issue for finish machining the assembly interface of the large-scale component, as it plays a crucial role in ensuring security and reliability in the finish machining system. To overcome the interoperable problems caused by different proprietary interfaces and communication protocols, this paper proposes an MTConnect compliant monitoring system for acquisition and supervision of the pivotal data during the finish machining process. The framework of the finish machining system is introduced at first, in which the main components and the workflow are described. What is more, the vital procedure and the involved process data are pointed out. Then the MTConnect standard is used to model the finish machining system, including the architecture and the data items. Based on the presented MTConnect model, a web-based monitoring system is developed for data collection and monitoring while machining the assembly interface of the large-scale component. The validity and the interoperability of the proposed approach are verified by collection and monitoring of the process data during finish machining the assembly interface of a vertical tail.

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Keywords: Large-scale component;fixture ;alignment; monitoring; MTConnect.

Nomenclature

AMT	Association for Manufacturing Technology
CNC	Computer Numerical Control
HTML	Hyper-Text Markup Language
HTTP	Hyper-Text Transfer Protocol
IPC	Industrial Personal Computer
LDAP	Lightweight Directory Access Protocol
OMAC	Open Modular Architecture Control
PAC	Programmable Automation Control
STEP-NC	Standard for the Exchange of Product Model Data for Numerical Control
TCP/IP	Transmission Control Protocol/ Internet Protocol
URI	Uniform Resource Identifier
XML	eXtensible Markup Language

1. Introduction

Assembly process is an essential aspect of the aircraft manufacturing [1]. Final assembly is a conclusive procedure which aligns and joins together the large-scale components such as fuselage, wings, tails, etc. Part-to-part assembly is usually infeasible in the final assembly process owing to dimensional variations caused by pre-assembly errors and temperature changes [2,3]. It is uneconomical and sometimes unprocurable to achieve interchangeability between the large-scale components by improving machining accuracy or subassembly precision. The feasible way is to pre-reserve allowance on the assembly interface, which is the interface region of the large component to be joined to the final product, for finish machining. Before final assembly, the allowance is fettled so that the component fits to the whole aircraft within the tolerance requirements [2].The assembly interface of a

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large aircraft component is generally very large in size, up to tens of meters. To ease the process of final assembly, the assembly interface of large component is usually composed of 2.5D machining features such as plane, hole, and step.

Monitoring is a critical issue in machining the complex and high-value product because it plays an important role in ensuring the security and reliability. The issue is especially serious for finish machining the assembly interface of the large-scale component, as it is the last machining process before assembling the large-scale component to the final product. Zero scrap must be achieved because it would cause a huge economic loss and extend the production cycle greatly if the component is rejected in the finish machining process. Moreover, the finish machining system is usually very complicated, consisting of various equipment and procedures. Therefore, it is essential to monitor the machining process to ensure machining precision and avoid a rejection.

There are various types of equipment on the shop floor of aircraft manufacturing, and the finish machining equipment is just a little part in them. Each of the equipment has its own proprietary interface and communication protocol, which poses a great challenge to the interoperable monitoring of the machines. Hence, there is a need for standardized interfaces for machine tools and other manufacturing equipment, bringing tight integration and interoperability [4]. Understanding the need for an open communication standard in manufacturing, the AMT has developed MTConnect [5]. MTConnect is a set of open, royalty-free standards intending to foster greater interoperability between controls, devices, and software applications by publishing data over networks using the Internet Protocol.

Currently, MTConnect has been adopted primarily by machine tool manufacturers and their end-users who see immense value in being able to interoperate with other equipment [6]. More and more researches have been made on the applications of MTConnect. Michaloski et al [7] have proposed a Web-enabled, real-time quality data and statistics based on MTConnect. Vijayaraghavan and Dornfeld [8] have used MTConnect to monitor the energy consumption patterns in the manufacturing system. Campos and Miguez [9] have introduced MTConnect into the data collection for traceability of the CNC. Liu et al [10] have studied on the networked monitoring technology of CNC machine tools based on MTConnect. Shin et al [11] have developed a STEP2M model to generate MTConnect machine-monitoring data from STEP-NC. Atluru and Deshpande [12] have used MTConnect in developing the communication interfaces with the on-machine probe on a CNC machine tool for Statistical Process Control.

From the literature reviews, it can be observed that MTConnect and the applications based on it has been studied and used more and more widely. However, MTConnect is still under development to cover more applications and information. For example, fixturing information, which is an important aspect in complex machining system especially for the easily deformable part, is not taken into account yet. To validate the performance and the extensibility of MTConnect in a complicated machining system, this paper introduces MTConnect into the data collection and process monitoring during finish machining the assembly interface of the large-scale component. The framework of the finish machining system is proposed in section 2. The MTConnect model of the finish machining system is described in section 3. The implementation of the monitoring system in presented in section 4. Section 5 demonstrates the monitoring of some key data in the machining process. Discussion and conclusion is given in section 6.

2. Description of the finish machining system

2.1. Framework of the finish machining system

A parallel machining framework is proposed as shown in Fig.1, in which the machine tool and the large-scale component are set up separately. A vertical tail of a large passenger aircraft is illustrated as an example in Fig.1.

In this framework, the workspace of the machine tool only needs to cover the machining region of the large component, which is economic saving [13]. Considering that the features to be machined are usually very simple rather than sculptured surface, a three-axis machine tool is capable of executing the machining task in the condition that the large component is aligned accurately. The large component is held and adjusted by the CNC positioners. The number of required positioner depends on the size of the large component, but is at least three. The holding device is used to hold and clamp the large component to maintain stability during machining process, and to reduce deformation of the large component caused by cutting force and other factors. The laser tracker is adopted to measure the large component to provide data for posture evaluation.

The CNC system handles all the motion controls including aligning, clamping and machining. Siemens 840Dsl controller with two channels is used to control the motions. The machining tasks are controlled by channel one, while the aligning and clamping tasks are controlled by channel two. The IPC is used to run the process control software which controls the aligning process.

2.2. Workflow of the finish machining system

The workflow of the finish machining system for the assembly interface is explained as follows:

Step 1: Measure the large-scale component by using the laser tracker.

Step 2: Evaluate the posture parameters of the large-scale component, and judge whether the posture parameters satisfy the tolerance requirements. If not, continue from Step 3. If so, continue from Step 4.

Step 3: Adjust the position and orientation of the large-scale component by means of the CNC positioners, and then restart from Step 1.

Step 4: Clamp the large-scale component by using the holding device.

Step 5: Fettle the assembly interface to clear the allowance on it.

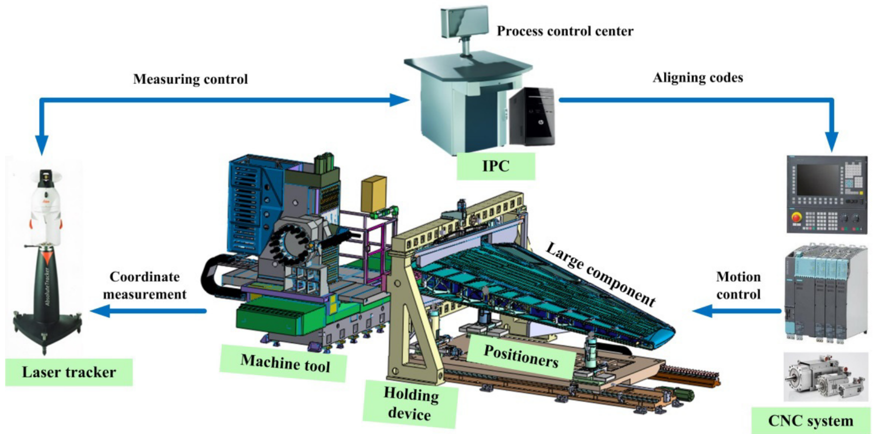

Fig.1 Framework of the finish machining system for the large-scale component

2.3. Pivotal process and data

The pivotal procedures that need to be monitored are from Step 3 to Step 5, i.e. posture adjustment, clamping and machining process. These procedures make direct impacts on the machining accuracy and stability. These processes and the key data involved are explained as follows:

- Posture adjustment

This process is executed by the CNC positioners, which are joined to the large-scale component by a sphere hinge, as shown in Fig.2.

Each positioner has a force sensor on it to monitor the holding force. When the large component is going to fall off during the adjustment process, the holding force would decrease quickly and an alert signal would be given to stop the process. Besides, to maintain stability and avoid damage, the motion parameters of the positioners such as position, velocity and acceleration also deserve to be monitored.

- Clamping and machining

The holding device consists of a main clamping component, an assistant internal support component and an assistant external clamping component, as shown in Fig.3. The main clamping component clamps the half jigs which hold the vertical tail. The assistant internal support component and external clamping component clamps the region near to the assembly interface to avoid deformation and shift caused by cutting force. All the clamping components have a force sensor mounted on the clamping head. Servo motors are adopted to control the clamping forces.

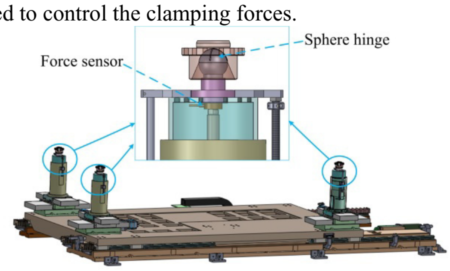

Fig. 2 Force sensors on the positioners

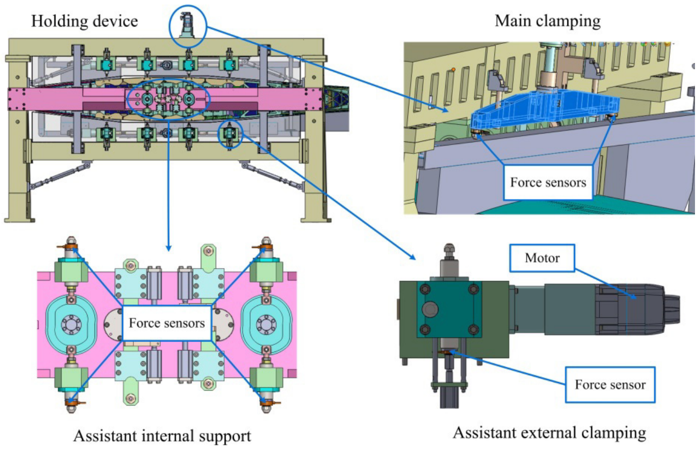

Fig. 3 Force sensors on the holding device

The assembly interface usually adopts a material with excellent mechanical property like titanium alloy to maintain reliability and safety, which is thin-wall and light, but difficult to cut. Hence, it is important to monitor the clamping force to avoid deformation or even damage caused by overlarge clamping force. Besides, lots of heat is released while cutting titanium alloy and thus the monitoring of coolant system is also necessary.

3. MTConnect model of the finish machining system

The MTConnect model of the finish machining system is an XML data model that is comprised of two primary types of XML Elements: structural elements and data elements. In the MTConnect standard, structural elements are defined as XML elements that describe the physical and logical parts and sub-parts of a device. Likewise, data elements are defined as XML elements that describe data that can be collected from a device.

The proposed information model of the finish machining system based on MTConnect is illustrated in Fig.4. The finish machining system is defined as a Device named as VTMS_machine, mainly consisting of four components which are described as below:

- *Controller*

Controller represents an intelligent part of a Device which monitors and calculates information that alters the operating conditions of the Device and the other Component and Subcomponent elements of the Device. Typical types of controllers for a piece of equipment are CNC, PAC and so on. In this paper, the controller refers to the CNC controller, names as Siemens 840Dsl. The data items involved in the controller mainly consist of Tool number, Controller mode (manual, automatic, etc.), Execution status (ready, active, feed_hold, etc.) and Program.

- *Axes*

Axes provide the information for structural elements that perform linear or rotational motion for the Device. The Axes component of the VTMS_machine has two subcomponents, and they are the aligning axes and the machining axes respectively. There are three linear axes and one rotary axis on the machine tool, which are controlled by channel one of the CNC system. There are three linear axes on each positioner, which are controlled by channel two of the CNC system. A force sensor is mounted on the Z axis of each positioner.

The data items provided by the linear axes consist of position, feederate and acceleration of the axes. Besides, the Z axis of each positioner provides an additional data item, i.e. the supporting force output by the force sensor. The rotary axis rotates about Y axis, so it is named as “B” according to the MTConnect standard. The data items offered by the rotary axis include rotary velocity and rotary mode.

- *Systems*

According to MTConnect standard, System is a functional sub-system of a Device such as a hydraulic system, a pneumatic system, a coolant system and so on. This paper focuses on the coolant system of the finish machining system, as has been explained in subsection 2.3. The data item provided by the coolant system is the fill level and the pressure of the coolant oil.

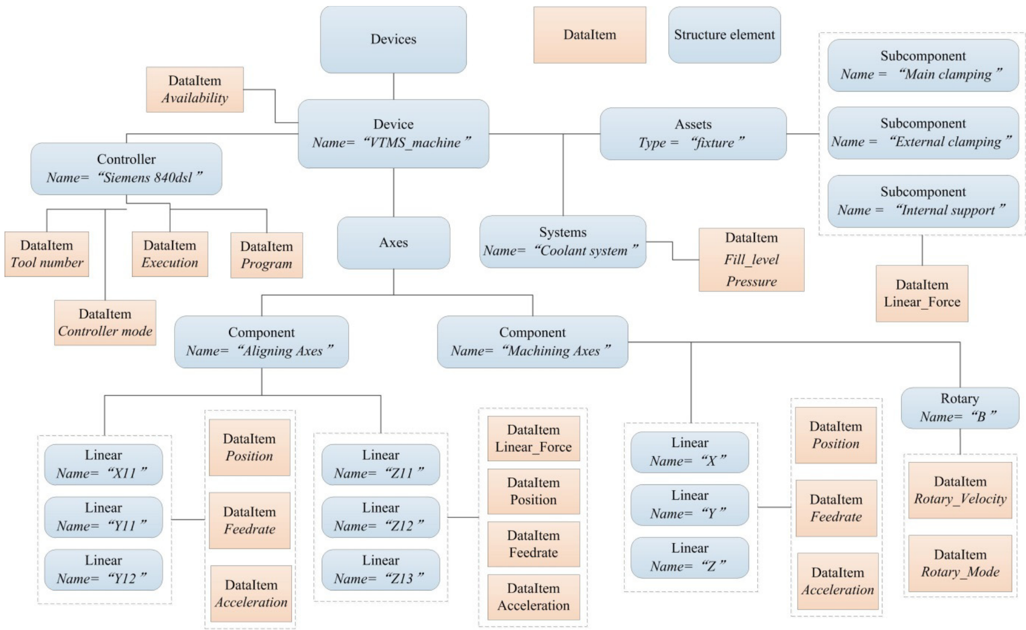

Fig.4 MTConnect data model of the finish machining system

- *Assets*

An Asset is something that is associated with the manufacturing process that is not a component of a device, can be removed without detriment to the function of the device, and can be associated with other devices during their lifecycle. Concrete examples of Assets are things like cutting tools or fixtures. Cutting tool is the first asset type covered by MTConnect standard. This paper extends the standard to cover the fixtures. The fixtures asset consists of three components: main clamping, internal support and external clamping, which have been briefly described in subsection 2.3. Clamping forces are the data items provided by the fixture asset.

4. Implementation of the monitoring system based on MTConnect

There are several different architectures to implement an MTConnect based monitoring system, according to whether an adapter is needed and where to implement the agent. The Siemens 840Dsl controller adopted in this paper cannot output MTConnect compliant data, and thus an adapter is required. The implementation architecture of the monitoring system based on MTConnect is illustrated in Fig.5.

The adapter is integrated into the agent and the agent is built into the IPC on the shop floor. The client is used to send HTTP request and get monitoring data. The integrated agent is developed by using C++ in visual studio 2013, and the agent is the core of the monitoring system. The integrated software communicates with the 840Dsl controller by TCP/IP protocol. A listening socket is created to receive and read the key data sent by the controller. The received data is transformed to the data format defined in MTConnect.

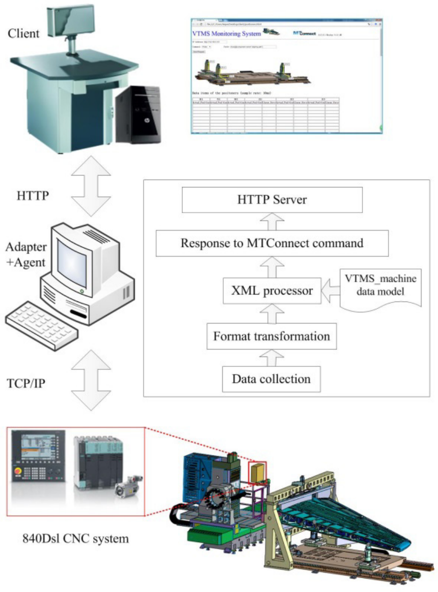

Fig.5 Implementation architecture of the monitoring system

The transformed data is written into the XML elements based on the proposed MTConnect model of the finish machining system. The data are ordered by time sequence. The integrated agent communicates with the client by HTTP, and it plays the role as an HTTP server. When a request sent by the client is received, the agent would make corresponding response. The agent can only handle four types of commands: probe, current, sample and asset.

The client is developed in the chrome web browser by using Macromedia Dreamweaver 8.0. Before the monitoring process starts, the agent is opened at first to connect with the VTMS_machine and to collect and store data posted by the controller. Then run the client to query the name of the agent by the LDAP service. After that, connect the client to the agent by the obtained URI. The probe command is sent primarily to get the data information that could be provided by the agent. At last, the cared process data could be monitored by sending the corresponding commands.

5. Case study

5.1. Sample request

The sample request is to get a sample of data items from the VTMS_machine. The sampled data could be filtered by a specified path. Fig.6 illustrates the returned data by sending a sample request filtered by the following path:

"path=//Axes// Components[@name="Aligning axes"] // DataItem[@type = "POSITION" and @subtype= "ACTUAL" or @type= "LINEAR_FORCE"]"

The retrieved data is the actual position and supporting force of the aligning axes. The units of position and force are millimeter and Newton respectively in MTConnect, so they are omitted on the client interface. Only a little part of data is displayed in Fig.6 due to the limitation of length. According to the whole monitoring data, the supporting force is stable during the aligning process.

5.2. Asset request

The asset request is to get the asset data from the VTMS_machine. The asset data could be filtered by a specified type. All the clamping force information of the fixture assets is retrieved by sending an asset request:

"Assets[@type=fixture]//DataItem[@type="LINEAR_FORCE"]"

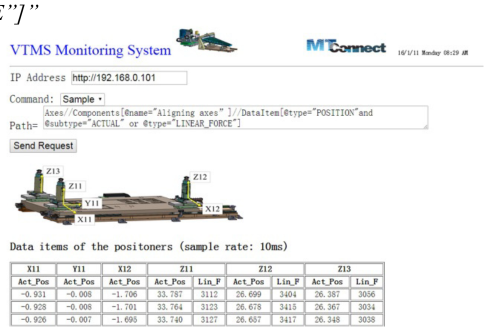

Fig.6 Process data of the positioners

The retrieved data is the clamping force of the holding device. The unit of the force is Newton as defined in MTConnect, and thus it is omitted on the client interface. Fig.7 shows a little part of the monitoring data, and the clamping force is stable during the machining process according to the intact data.

6. Concluding Remarks

This paper introduces an MTConnect based monitoring system for finish machining the assembly interface of a vertical tail on a large passenger aircraft. An MTConnect model of the finish machining system is proposed. Based on the model, the agent software is built with integration of an adapter to collect the process data and to transform the data format. The agent software sends the data in a standard format to the client. The validity and the interoperability of the proposed system are verified by monitoring some key data in the aligning, clamping and machining process. In this work, there are some issues that worth to be discussed.

(1) The data involved in the pivotal process in this finish machining system could also be collected and monitored by other numerous solutions. Therefore, it is not the advantage of MTConnect to just get and monitor the process data. Instead, the unified standard format to represent the data and the HTTP+XML based process which lead to a plug-and-play atmosphere are the benefits to adopt MTConnect.

(2) The fixture information is integrated into the MTConnect model as assets of the finish machining system, but it is not covered by the MTConnect standard yet. However, extensibility is a key feature of the MTConnect standard, which has been validated by the case study.

(3) The benefits of using MTConnect are not completely displayed in monitoring this finish machining system. When the whole shop floor including many other machines needs to be monitored, the benefits offered by MTConnect would greatly increase. Because data from multiple machines would have a common definition – name, units, values, and context, and this would ease the realization of integration and interoperability of the machines.

(4) The process data collected from the VTMS_machine could also be used to optimize the aligning and machining process in addition to the supervision of the process. For example, the machining process parameters such as cutting depth, feeding speed, etc. could be optimized according to the variation of clamping force during the process. This will conduce to the realization of intelligent manufacturing.

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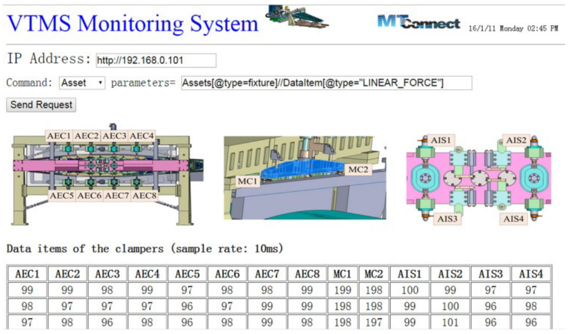

AEC1	AEC2	AEC3	AEC4	AEC5	AEC6	AEC7	AEC8	MC1	MC2	AIS1	AIS2	AIS3	AIS4
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98	97	97	97	96	97	99	99	198	198	99	100	96	98
97	98	96	98	96	98	99	98	198	197	99	101	96	96

Fig.7 Process data of the clampers

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