Chapter 7

Data Monitoring and Management for Machine Tools

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7.1 Introduction

Twin-Control concept combines the development of holistic simulation models with the knowledge of the performance of the real machines and processes. To deal with this second part, a data monitoring infrastructure must be implemented so that required information is acquired, managed and analyzed properly.

The approach used in Twin-Control consists in the installation of a local monitoring hardware that acquires internal variables of the machine, collects data of additional sensors and uploads all data to a cloud platform [1]. ARTIS Genior modular is used for the local monitoring, and PREDICT's KASEM[®] is used as cloud platform for data analysis. A fleet-level data analysis will be performed by integrating all the information coming from the different machines.

This chapter is structured as follows. After a brief introduction, an overview of the equipment to be monitored and integrated in Twin-Control is presented. The

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Fig. 7.1 Map of Twin-Control monitored and connected machine tools

third-section presents the different architectures proposed to cover all the use cases. Finally, the conclusions are presented.

7.2 Monitored Equipment

Figure 7.1 presents all the machine use cases monitored in Twin-Control project. As it can be observed, a total of 12 machine tools have been monitored. Each of the industrial validation scenarios includes three machines. For the aerospace validation scenario, located at MASA aerospace structural manufacturer installations (Agoncillo, Spain), three GEPRO machines were selected as use cases, named as Use cases 1–3. The machines present a similar architecture, but they differ in the number of axes and spindles. For the automotive validation scenario, located at RENAULT automotive component manufacturer (Cleon, France), three COMAU Urane machines were selected, named as Use cases 4–6.

Three more use cases have been monitored to test and validate Twin-Control developments during the project:

- Use case 7: CHIRON milling machine, located at ARTIS (Egestorf, Germany), to validate monitoring tools and test new features (NC Simulation).
- Use case 8: GORATU 5 axis milling machine, located at TEKNIKER (Eibar, Spain), to validate machine tool characterization procedure.

- Use case 9: EMAG machine, located at the ETA-FACTORY (Darmstadt, Germany), to test and validate energy efficiency models.

Finally, three additional machines, located at relevant research locations, have been taken to implement Twin-Control features and present them to the scientific and industrial community:

- Use case 10: Starrag EcoSpeed milling machine, located at the AMRC (Sheffield, UK), to disseminate process models and monitoring developments.
- Use case 11: GMTK vertical lathe, located at the recently opened Basque Advance Manufacturing Centre (Zamudio, Spain), to show Machine Tool characterization procedure, among other features.
- Use case 12: a second EMAG machine, located at the ETA-FACTORY (Darmstadt, Germany), to promote energy efficiency features.

The different use cases show a heterogeneous mixture of CNC models and communication-field buses, which represent the typical state for machine tool users. With this variety, it is difficult to determine a unique local monitoring architecture. In the next section, the different implemented architectures are detailed.

7.3 Implemented Monitoring Architecture

In each use case, monitoring hardware has been installed. Figure 7.2 presents a diagram showing the generic monitoring architecture used in Twin-Control project. However, depending on use case specifications and requirements, this generic architecture is adapted.

The modular configuration provided by ARTIS is perfectly suited to cover the heterogeneous applications. Figure 7.3 shows the integrated hardware in two of the industrial use cases.

ARTIS Genior modular (GEM) is the data acquisition module that can get real-time CNC/PLC data (around 100 Hz sampling, depending on the application). Also, an HMI visualization with any PC which is connected to the plant network is possible. For the real-time connection with the CNC, two different protocols are available. For the aerospace use cases, with FAGOR 8065 CNCs, an ARTIS FAGOR-CANopen protocol has been developed. This protocol allows a real-time monitoring of 32 bytes per sample. For the Twin-Control project, 28 bytes have been used to process data and 4 bytes have been reserved to identification and process information. To increase the number of possible real-time monitored signals, the CANopen sample rate was reduced to 4 ms. By combining two CANopen channels, real-time monitoring of 56 bytes (24 variables) with a sample rate of 8 ms is provided. For the machines located at the automotive validation scenario, mounting SIEMENS 840D CNC, PROFIBUS protocol is used to connect ARTIS GEM with machines PLC. This protocol enables system to exchange up to 16 CNC sensor signals in parallel. For some other use cases, as GORATU machine located at TEKNIKER, two of these devices are installed to increase the real-time monitoring variables up to 32.

Fig. 7.2 Generic monitoring architecture applied in Twin-Control project

Fig. 7.3 Monitoring hardware installations in Twin-Control: **a** COMAU Urane machine from automotive validation scenario; **b** GEPRO 502 machine from aerospace validation scenario

Depending on the use case and its requirements, different variables have been configured to be monitored. Also, for each variable, it has been defined if real-time information is needed. As a sample, the real-time variables monitored in the two industrial validation scenarios are presented in Table 7.1.

Using the ARTIS GEM device, visualization of monitored data in machine tool HMI (Fig. 7.4) is possible for Windows XP-based controllers, using Ethernet connection and the GEM-Visu software.

ARTIS Online Process Recorder (OPR) is connected to the GEM for data storage purposes (240 GB capacity). It is also capable of monitoring non-real-time data using OPC, as a second data source. In addition, GEM and OPR could exchange real-

Table 7.1 Example of real-time (10 ms sampling) variables monitored in machines from aerospace and automotive validation scenarios

Aerospace validation scenario Gepro 502	Automotive validation scenario COMAU Urane
Target position X	Target position X
Target position Xb	Target position Y
Target position Y	Target position Z
Target position Z	Target position B
Target position A	Real position X
Target position B1	Real position Y
Real position X	Real position Z
Real position Xb	Real position B
Real position Y	Real power X
Real position Z	Real power Y
Real position A	Real power Z
Real position B1	Real power B
Real position B2	Spindle torque S
Real position B3	Torque X
Real power X	Velocity Y
Real power Y	Machine true power
Real power Z	ACC X
Real power A	
Real power B1	
Spindle torque S1	
Spindle torque S2	
Spindle torque S3	
Spindle speed S2	
Machine true power	

time information using CANopen, for example, in case of critical alarm information remotely detected inside the data management system (KASEM®).

ARTIS OPR shows a special feature in the EMAG machines located at the ETA-Factory (Darmstadt, Germany). Since the energy models are based on ON-OFF switching signals of the Bosch Rexroth control and the machine power aggregates, an OPC-UA interface has been developed. The energy efficiency models, developed in MATLAB/Simulink, are running at the OPR, and the signals are read from the control via OPC-UA. By using ARTIS GEM as additional software, it is also possible to monitor the energy model results in the GEM and visualize the results in the GEM-Visu (Fig. 7.5).

As an example, Table 7.2 presents the non-real-time variables monitored by the OPR devices installed in the industrial validation scenarios.

Table 7.2 Example of non-real-time (1 s sampling) variables monitored in machines from aerospace and automotive validation scenarios

Aerospace validation scenario Gepro 502	Automotive validation scenario COMAU Urane
Time	Time
Spindle speed S1	Process mode (G 00/G 01)
Spindle speed S2	Hydraulic system status
Spindle speed S3	High pressure cooling status
Hydraulic system status	Low pressure cooling status
Spindle temperature S1	Workpiece counter
Spindle temperature S2	FMD signals
Spindle temperature S3	Part info for RENAULT
Backlash X	RMS (15–1000 Hz)
Backlash X1	RMS (15–5000 Hz)
Backlash Y	RMS (5% around RPM tool 4)
Backlash Z	RMS (5% around RPM tool 12)
Backlash B1	RMS (5% around RPM tool 15)
Backlash B2	
Backlash B3

Fig. 7.6 Hall sensors installed in the main electrical input for energy monitoring purposes in GEPRO 502 machine from aerospace validation scenario

of 25 kHz, a new firmware for the VM module was developed and installed. This firmware stored the vibration data with a sample frequency of 25 kHz at the OPR. Inside the OPR, an automatic analyzing function was developed, which calculate the

Fig. 7.7 ARTIS DDU-4 K-Wisy wireless force monitoring device from MARPOSS monitoring solutions

RMS values for five frequency bands and send the result continuously via GEM to the GEM module (Table 7.2).

ARTIS DDU-4K-Wisy (Fig. 7.7) is a new device from MARPOSS Monitoring Solutions that has been installed in the Starrag EcoSpeed machine, located at the AMRC (Sheffield, UK). It consists in a tool holder with embedded force and temperature measurement capabilities that is used for in-process force monitoring. The DDU 4K-Wisy is based on a HSK 32 tool holder which is equipped with eight strain gage rosettes each containing two mutually perpendicular grids. Via this measurement configuration four different measuring values are captured: torque, axial force and the axial tool holder deflection in two directions (perpendicular). To acquire temperature-compensated signals, each pair of strain gages is interconnected to four separate Wheatstone bridges. To log the generated data, a wireless transmission on the ISM radio band (around 2,4 GHz) is used along with a corresponding radio receiver which either can be connected to ARTIS monitoring devices via CAN bus or to a standard PC via USB.

7.4 Cloud Data Management

Fleet-wide proactive maintenance functionalities consist of the construction of model coupling data analytics and expert knowledge. Raw data and machine-level computed

information are therefore a major input of the cloud platform which is powered by PREDICT’s KASEM® solution. The platform is accessible via the Internet and hosted on a secure server.

Data transfer from machine to the platform requires some flexibility to match with IT and production constraints. Indeed, in factories, machine tools are connected a production Ethernet which is used to exchange synchronization information between machines, gantry, robots and various management and control systems. Depending on the size and the age of the factory, networks can be close to saturation and a continuous transfer of high sampling rate data could impact the network availability and introduce losses of information packets. In addition, from cyber-security point of view, IT department is often reluctant to “connect” production network to the Internet because bad-intentioned people could get into the network and take control of equipment for instance.

In view of these constraints, various data transfer architectures have been applied according to use cases. In case of laboratory and pilot machine tools, OPR has a direct connection to the cloud platform. For the industrial use cases, intermediate servers have been used, and these servers are connected to the production network and enable local data storage and edge computing. For the aerospace scenario, data from the OPR is automatically uploaded to the local KASEM® platform inside MASA facilities through MASA network; then this server, also connected to the Internet, manages the data transfer to the cloud as depicted in Fig. 7.8. In this case, local server also acted as a partition between machine network and Internet.

For the automotive scenario, IT constraints were more important, and to enable the data transfer a specific architecture has been developed in collaboration with the IT architects. This architecture is also based on a local platform hosted in a RENAULT data centre in the Renault Technocentre (Guyancourt, France) and connected to the production network as shown in Fig. 7.9. Server S1 hosts KASEM® solution, and knowledge base is hosted by server S2. Server S3 is a file storage server used for binary files. Finally, an intermediate Renault/Nissan system is used for secure transfers between the local and fleet platforms. In this case, architecture management—installation, configuration and update—can be made only from user connected to Renault network.

Fig. 7.8 Data exchange configuration for the aerospace validation use case

Fig. 7.9 Data exchange architecture for automotive use case

About every 10 min, each machine—OPR module—sends and receives real-time data from/to the local or fleet platform which represents around 5 MB transferred in batch mode. About every 60 min, each machine—OPR module—sends and receives non-real-time data from/to the local or fleet platform which represents around 6 MB in batch mode. The total amount of data stored per machine could be 600 GB per year. Inside KASEM[®] platform, there is a specific service able to index, read and archive binary with a life cycle management of acquisition channels. Regarding transfer protocols, WebDAV and FTP are the default options for upload stream. Once the Internet connection is set up and running, it is possible to download and see a report generated by KASEM[®] with the Genior modular HMI Plug-in.

Cloud platform is accessible at <https://twincontrol.kasem.fr>, with restricted access to authorized users. A screenshot of the home page of KASEM[®] platform is shown in Fig. 7.10. This interface provides the chance to visualize collected time series, computed information and stored reports, download data, and even advanced tasks like indicator generation via algorithm implementation.

Fig. 7.10 Home page of KASEM server showing the connected use cases in the data management system

7.5 Conclusions

This chapter presents the monitoring infrastructure installed in a total of 12 machines used for implementation of Twin-Control at different levels: industrial evaluation, scientific validation and dissemination.

At local level, the monitoring architecture is based on a modular configuration. ARTIS devices are used and configured according to each use case specifications and requirements. The modular system can synchronously acquire internal variables from the CNC/PLC (real-time and non-real-time data), as well as signals from additional sensors like accelerometers, hall sensors and force transducers. This flexible approach provides the opportunity to include a wide range of equipment in the monitored fleet and is perfectly adapted to the usual configuration of end-users, with very different machines in their installations.

The data monitored at local level is uploaded from ARTIS OPR modules to a cloud platform. The PREDICT's KASEM® platform has been storing information from most of the use cases during almost two years in Twin-Control project. Hence, the proposed architecture has been validated and has provided an excellent source of real data used as a basis for the rest of developments of Twin-Control.

The capabilities of the installed infrastructure are not limited to data monitoring and storage. In following chapters, other capabilities like advance indicator calculation, fleet analytics and even the possibility to integrate model-based control actions in the machine will be covered.

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