Series
Toward Realization of Smart Manufacturing Systems

Case: Collaborative design and implementation of monitoring/visualization system considering diversity of machine tools

Executive summary

Robot Revolution Initiative
WG for manufacturing business revolution through IoT
The Industrial Machinery Steering Committee

April 2018

Committee members:

Supported by
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1. Overview

In this year, the Industrial Machinery Steering Committee has conducted a study of common expression of data obtained from machine tools, which enables knowledge and information sharing among a variety of machine tools so that their user can easily integrate them into a cyber physical production system regardless of tools types and manufacturers. The study has been conducted in context of two cases: planning and scheduling of maintenance of machine tools (Case 1) and quality control with sufficient traceability of production data (Case 2). In both cases, decision makings require intensive integration of the data of machine tools in a production line. Information processing procedures for the both cases are also designed through identification of requirements for a software system that visualizes when each machine tool should be maintained and how manufacturing condition changes during a series of production. For Case 1, we have identified 19 data items through detailed analysis of six activities for collecting necessary information for estimating the residual life of each component of machine tools (see Section 2).

For Case 2, we have identified 16 data items that are used for identifying the point of variation in machine shop tool conditions, work setting, and NC program (see Section 3).

We have also designed a standard data format for the both cases, each of which contains the data items identified above. A prototype monitoring/visualization system is developed and demonstrated through an intensive collaboration among members of the Industrial Machinery Steering Committee based on the
information processing procedure and the data format described above.

2. Case 1: Planning and scheduling of maintenance of machine tools

In this case, we have identified common data items regarding maintenance of machine tools considering physical deterioration of durable parts and cumulative usage of consumables. For each maintenance item such as refilling of coolants and replacement of tool chips, regardless of the types (and the manufacturers) of machine tools, the residual life, which is regarded as a common data item, is computed based on more primitive common data items locally stored by individual machine tools. The information about the residual life obtained from individual machine tools can be further used for planning and scheduling of maintenance of machine tools. As a result of intensive discussions among the committee members as well as engineers in diverse machine tools manufacturers, we have identified 19 common data items as shown in Table 1 (i.e., ActivityID, ActivityString, SubjectID, SubjectString, ObjectID, ObjectString, Time, ClockID, ClockString, MaintenanceItemID, MaintenanceItemString, MeasuredValue, MeasurementMethod, ResetValue, MaintenanceMethod, ThresholdValue, ThresholdSettingMethod, ComputedMaintenanceTime, Computation Method). Such common data items are associated with specific activities such as machine tool operations, maintenance executions, monitoring and adjustment of threshold values regarding each maintenance item.

3. Case 2: Quality control with sufficient traceability of production data
Due to inevitable wear and failure of machine tools as well as time variations in production environment such as temperature, humidity and so forth, manufacturing conditions generally change during a series of production. These changes in manufacturing condition cause unexpected variation in production quality. Therefore, sufficient traceability of production data is essential for quality control. In order to identify the changes in manufacturing conditions that might cause the deterioration in production quality, simultaneous visualization and monitoring of their point of variation and production quality are indispensable.

Among a variety of changes that can cause deterioration in production quality, we have especially focused on those in machine shop tool conditions, work piece setting, and NC program in this year. As a result, we have identified 16 common data items (i.e., DataID, DataGenerationTime, MachineID, GetTime, WorkID, TCode, TCodeString, SequenceNumber, ToolID, ToolOffsetID, ToolOffsetString, WorkOffsetID, WorkOffsetString, ProgramID, ProgramString, OperationStatus) as shown in Table 2. As six machine tools that are used in this study do not uniquely specify the machine shop tool they are using, the work piece they are processing, and the program they are using in general, the procedure for assigning unique ID to each machine shop tool, work piece, and program change are also designed in this study.

4. Design and implementation of machine tools monitoring system

We have developed a prototype monitoring/visualization system for the both
cases, of which overall structure is depicted in Fig. 1. The monitoring and visualization system consists of machine tools, edge PCs attached with machine tools, and two server PCs (i.e., server 1 and 2). Each edge PC periodically obtains the values for each data item in Tables 1 and 2 and upload them to the server 1 periodically (i.e., around 24 hours and 15-30 seconds for the cases 1 and 2, respectively). The server 1 uploads the data to the cloud called “IoT platform,” based on which the server 2 renders the screen of the monitoring and visualization system of machine tools. We have separately implemented the visualization and monitoring system for the both cases and these systems are hosted by the server 2.

Figures 2 and 3 show the hardcopy of the application program for Case 1. The table in Fig. 2 shows the residual life of each component (e.g., air filter, lubricating oil for automatic tool changer, and so forth) of machine tools. The horizontal and the vertical axis of the table correspond to future dates and components of machine tools, respectively. The colors in each cell represent the status of the corresponding component at future date (e.g., 3 days after today). The cells in red, orange, and green indicate that the corresponding component will be fine, will have a certain possibility of malfunction, and will need maintenance at the corresponding date, respectively. Fig. 3 simultaneously shows the residual life of and the tasks assigned to each machine tool for next six months. In contrast to Fig. 2, which shows the status of each component of machine tools, Fig. 3 shows the status of machine tools that constitute a production line of users. By referring to the screens given by Figs 2 and 3, users can easily identify the components to be maintained and determine the maintenance schedule of each machine tool.
considering its production schedule. Note that the system can work well even when these machine tools are located at different sites because the system has been implemented as web-based application as shown in Fig. 1. In addition, the system also works well when the production system even consists of a variety of types of machine tools made by different manufacturers, because the system is implemented by using the common data items identified in Section 2.

Figure 4 shows the hardcopy of the application program for Case 2. The left hand side of Fig. 4 plotted the variation in manufacturing conditions of each machine tool. The horizontal and the vertical axis of Fig. 4 correspond to the manufacturing conditions in each machine tool and the works processed in a given manufacturing system, respectively. Plots in red, green, and blue represent the change in NC program, tool replacement, and the change in tool offset, respectively. For example, the plot in red encircled by red dotted line represents that the NC program of machine tool “MAZAK” had been changed just before it processed the work “13002”. The right hand side of Fig. 4 shows the inspection results of each work. By referring to the point of changes in manufacturing conditions and the inspection result of each work at the same time, it is possible to identify the changes that can cause the failure or deterioration of production. For example, the right hand side part of Fig. 5 shows the quality of the works “16003,” “16007,” and “16008” is not sufficient. Referring to the corresponding changes (e.g., two plots encircled by the red dotted line for the work “16003” and those encircled by the blue dotted line for the works “16007” and “16008”) plotted in the left hand side of Fig. 5, the user of the system can infer some changes in NC program of machine tool “Fujitsu-1” and the tool replacement without updating
tool offset can be the reasons for insufficient quality of the works.

The prototype system is demonstrated by using multiple machine tools located in seven different sites with a work piece depicted in Fig. 6, and the feasibility and the validity of the system as well as the common data items described in Sections 2 and 3 are confirmed.

Acknowledgement

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Figures and Tables

Figure 1 Prototype monitoring/visualization system used for Cases 1 and 2

Figure 2 Hardcopy of the application program prepared for Case 1 (1)
Figure 3 Hardcopy of the application program prepared for Case 1 (2)

Figure 4 Hardcopy of the application program prepared for Case 2
Figure 5 Identification of the changes that cause deterioration of production quality.

Figure 6 Work piece used in demonstration.
Table 1 Common data items identified in Case 1

<table>
<thead>
<tr>
<th>Index</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>ActivityID</td>
<td>Identifier for the type of activity</td>
</tr>
<tr>
<td>1</td>
<td>ActivityString</td>
<td>String explaining the contents of activity</td>
</tr>
<tr>
<td>2</td>
<td>SubjectID</td>
<td>Identifier for the subject of activity</td>
</tr>
<tr>
<td>3</td>
<td>SubjectString</td>
<td>String explaining the subject of activity</td>
</tr>
<tr>
<td>4</td>
<td>ObjectID</td>
<td>Identifier for the object of activity</td>
</tr>
<tr>
<td>5</td>
<td>ObjectString</td>
<td>String explaining the object of activity</td>
</tr>
<tr>
<td>6</td>
<td>Time</td>
<td>The time the activity is executed</td>
</tr>
<tr>
<td>7</td>
<td>ClockID</td>
<td>Identifier for the clock which is used in the activity</td>
</tr>
<tr>
<td>8</td>
<td>ClockString</td>
<td>Detailed description of the clock</td>
</tr>
<tr>
<td>9</td>
<td>MaintenanceItemID</td>
<td>Identifier for the maintenance items handled in the activity</td>
</tr>
<tr>
<td>10</td>
<td>MaintenanceItemString</td>
<td>Detailed description of the maintenance item</td>
</tr>
<tr>
<td>11</td>
<td>MeasuredValue</td>
<td>Measured value or status of the corresponding maintenance item</td>
</tr>
<tr>
<td>12</td>
<td>MeasurementMethod</td>
<td>Description of the measurement method.</td>
</tr>
<tr>
<td>13</td>
<td>ResetValue</td>
<td>Initial value that is set for each maintenance item when it is maintained.</td>
</tr>
<tr>
<td>14</td>
<td>MaintenanceMethod</td>
<td>Description of maintenance method.</td>
</tr>
<tr>
<td>15</td>
<td>ThresholdValue</td>
<td>Threshold values for the maintenance item determining whether the corresponding component needs maintenance or not.</td>
</tr>
<tr>
<td>16</td>
<td>ThresholdSettingMethod</td>
<td>Description of the threshold value.</td>
</tr>
<tr>
<td>17</td>
<td>ComputedMaintenanceTime</td>
<td>The time when the corresponding component should be maintained.</td>
</tr>
<tr>
<td>18</td>
<td>ComputationMethod</td>
<td>Description of the computation method of maintenance time</td>
</tr>
</tbody>
</table>
### Table 2 Common data items identified in Case 2

<table>
<thead>
<tr>
<th>Index</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>DataID</td>
<td>Identifier for the data itself.</td>
</tr>
<tr>
<td>1</td>
<td>DataGenerationTime</td>
<td>The time when the data file is created.</td>
</tr>
<tr>
<td>2</td>
<td>MachineID</td>
<td>Identifier for the machine tool</td>
</tr>
<tr>
<td>3</td>
<td>GetTime</td>
<td>The time when the records of the data are obtained.</td>
</tr>
<tr>
<td>4</td>
<td>WorkID</td>
<td>Identifier for the work that is processed in the machine tool at this time.</td>
</tr>
<tr>
<td>5</td>
<td>TCode</td>
<td>Identifier for the type of a machine shop tool that is used at this time.</td>
</tr>
<tr>
<td>6</td>
<td>TCodeString</td>
<td>Description of TCode.</td>
</tr>
<tr>
<td>7</td>
<td>SequenceNumber</td>
<td>Sequence number of NC program.</td>
</tr>
<tr>
<td>8</td>
<td>ToolID</td>
<td>Identifier for the tool used at this time.</td>
</tr>
<tr>
<td>9</td>
<td>ToolOffsetID</td>
<td>Identifier for the tool offset setting at this time.</td>
</tr>
<tr>
<td>10</td>
<td>ToolOffsetString</td>
<td>Detailed description of tool offset setting.</td>
</tr>
<tr>
<td>11</td>
<td>WorkOffsetID</td>
<td>Identifier for the work offset setting.</td>
</tr>
<tr>
<td>12</td>
<td>WorkOffsetString</td>
<td>Detailed description of work offset setting.</td>
</tr>
<tr>
<td>13</td>
<td>ProgramID</td>
<td>Identifier for the machine tool program.</td>
</tr>
<tr>
<td>14</td>
<td>ProgramString</td>
<td>Description of machine tool program.</td>
</tr>
<tr>
<td>15</td>
<td>OperationStatus</td>
<td>Operation status of the machine tool at this time.</td>
</tr>
</tbody>
</table>
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