A Knowledge-based Product Model Data for Integrating CAM-CNC Operation

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Abstract:
This paper describes a model of knowledge-based system for integrating CAM and CNC operations. In detail, the main concern of integration is driven by proposed standardized check list as a part of product data which is useful for capturing and managing the knowledge based activities done by CAM operators and CNC machine operators in assessing product data before proceeded into CNC machining process. With regard to the technical limitation concern, this system is focused on common CNC milling operations.

Keywords: CAM-CNC, Product data, Knowledge-based system.

1. Introduction

Currently, processes along manufacturing system have been greatly supported by introducing computer support technology and tools throughout the whole processes. Along process planning operation and CNC machining operation, the recent development on Computer Numerical Control (CNC) and Computer Aided Manufacturing (CAM) significantly have proven to offer contribution for realizing machining automation in industries amid manufactured products are increasingly complex [1].

Typically, the involvement of CAM application can be considered as the use of computer-based software tools that assist engineers and machinists in manufacturing or prototyping product components. Today’s CAM user can easily generate streamlined tool paths, optimized tool axis tilt for higher feed rates and optimized Z axis depth cuts as well as driving non-cutting operations such as the specification of probing motions [2].

In sense of its connectivity with prior and following manufacturing phases, CAM is a programming tool that makes it possible to manufacture physical models using computer-aided design (CAD) application. And the output from the CAM software is usually NC file which consists of G-Code, with usually many thousands of commands long, that is then transferred to the CNC machine. Therefore, indeed the need for CAM application by the manufacturing engineer, NC programmer or machinist is highly essential since only accurate NC codes should be passed up CNC machining process.

As for the development of accurate NC file, current status of all aspects in shop floor that possibly keeps changing is needed to be adopted and taken into account by process planner/CAM operator in order to come up with G-Codes which are able to be manufactured in well manner. However, sometimes, for example, the used tools that have been designed by CAM operator cannot be applied on to the machining process due to some reasons such as unavailability, tool wear, etc. As the consequence, CNC operator must take action on the product data in response to the current situation in shop floor.

Generally speaking, it is necessary to integrate processes along CAM-CNC operation in order to minimize the occurrence of inaccurate NC file by integrating the know-how of agents among the operations. In response to described situation above, this paper suggests a knowledge based model for integrating CAM-CNC operation. The rest of this paper is organized as follows: Section 2 contains conceptual approach in which basic idea of proposed system in comparison to existing common practices is elaborated. The concept of standardized check list and the development of knowledge-based system for capturing and managing CNC operator know-how are identified as the basic differentiation between proposed system and existing common system; in Section 3, the standardized check list is elaborated further in conjunction with the system architecture and the knowledge-based approaches. The system architecture comprises the structure of system in terms of description of graphical user interface (GUI) system, the flow of process and its connectivity scheme with database system.

The knowledge-based approaches are covering the knowledge elements determination and aspect of human flow of thinking. In the end of this section, the standardized check list is interacted with other domains by using simple example.

2. Conceptual approach

Conceptually, the approach is to develop a system aimed for supporting CNC operator in the shop floor in dealing with product model data, whether it is sufficient or not for further process. Respectively, such activities which are done by CNC operator can be considered as knowledge based activity.

In accordance, if its flow of processes as well as its results can be captured, documented and managed, it considerably will be beneficial for continuous improvement of the whole system. Because these activities are typically correlated not only with current
availability status of about equipments or tools, but also correlated with the know-how of CNC operator when coping with product data assessment and its decision making process. Indeed, learning from earlier projects/processes is essential to avoid recurrence of problems and is generally believed for realizing the collaboration scheme for integrating operations during product lifecycle [3].

Further, regarding another conceptual approach, it will be more beneficial when after being checked and assessed within the shop floor, the product data can be passed back to the previous phase, in this case - CAM operation phase. Meanwhile, in case of minor adjustment and common changes, it does not have to be delivered back to the CAM operation phase. The aim is to improve the ability of system to be able to manage bi-directional flow of product data in case of relatively major changes. Thus, not only forward flow is allowed within the system but also the backward flow according to current status on CNC operation side.

Those conceptual approaches are then adapted into more technical approach which is to improve the contents of product data. It is desired that product data should be able to take place as the key which connects all operations and allows the bi-directional flow of data, information and knowledge. The added content is so called standardized check list as a part of product data. It is designed to be useful for capturing and managing the knowledge based activities done by associated agents. By means of this, activities and results that occur during product data assessment performed by CNC operators can be captured and documented in such way so that it can be useful for following improvement on the product data and whole operation.

The described aspects above are depicted in Fig. 1 which also illustrates the comparison between common existing system and proposed system. The added check list as part of product data which is produced by the system embedded on CAM application, the knowledge based system for assessing the product data by accessing the check list, and the knowledge based system for capturing and managing the know-how of CNC operators can be seen on Fig. 1b. These all are considered as the difference and further improvement of common existing system depicted in Fig. 1a.

3. The design of knowledge-based system

3.1 Standardized check list

Regarding the standardized check list added onto the product data, adequate concern towards the use of CAM application must be extensively taken into account. In general, important items on the design of machining processes that accomplished by means of CAM application are comprehensively summarized and represented as standardized check list. The concern on how to select the important items should be based on the aspects which are allowed to be assessed as well as actions which are allowed to be done by CNC operators when dealing with inaccurate product data. This consideration substantially influences the selection on items of standardized check list.

As briefly mentioned in the previous section, these items will be the starting points of the product data assessment activity, and will be broadly correlated with all
other aspects, i.e. assessment approach, rules, target & constraints of the production, potential actions as well as its reasons why selected or eliminated, etc. These correlating elements will be then aggregated to come up with recommended actions. Along with correlating process, all should be related with flow of thinking of CNC operators, since it has to do with utilization of human know-how. And again, in case of bi-directional flow of product data, the process of redesigning rejected product data which is supposed to be passed back into CAM operation will be driven by associated items as well as its result of assessment issued by CNC operators. Accordingly, by taking aspects described above together with aspect of common CNC milling operations into consideration, the selected items can be seen on Table 1.

Concerning the approach on how to define these items, all are representing aspects that are typically faced by CNC operators to deal with product data in sense of availability and manufacturability concerns. Also, many typical adjustments on product data are done by CNC operator correlated with these items.

Meanwhile, speaking about standardized data model, CNC Data Model (ISO14649) as one of the detail extension of ISO10303 “Industrial automation system and integration - Product data representation and exchange”, known as STEP or Standard for the Exchange of Product Model Data, has been developed. Those are considered as interface standard for the CAD-CAM-CNC chain [4].

ISO14649 and ISO10303 are addressing a very broad range throughout the lifecycle of product data. On the other hand, the idea behind as well the approach on how to develop this proposed check list is focused on narrower aspect which is, as already mentioned, particularly about common changes/modification carried out by CNC operators. The purpose itself is practically meant for supporting the capturing process on action based know-how performed by CNC operators, as portrayed in Fig. 1b. Further as depicted in Fig. 2, all elements will be compiled become a certain soft file which is further will be opened in the expert system to be connected with the logical way of thinking of human, in this case are CNC operators. Simply speaking, this proposed check list is developed in order to build a soft-file that will provide basic data for the knowledge based system for assessing product data.

In the meantime, the structure of STEP standard (ISO10303) is addressing the exchanging mechanism of the product data itself as well as the whole geometric information which has to be exchanged along the process. ISO14649 and ISO10303 are considerably established meant for scenario depicted in Figure 1a. In contrast, the proposed check list is added into the system, as can be seen in Fig. 1b, in order to support and enable the realization scenario depicted in Fig. 1b.

As for the example, when thinking about availability concern, targeted machines and tools are sometimes utilized by other operations or breakdown due to maintenance. Another example, current performance level of particular tool is difficult to be determined by CAM operators, along with utilization period. Meanwhile, the prediction of current status of tools performance affects the determination of machining parameters such as ‘cutting speed’, ‘feed rate’ in conjunction with type of material depth of cut, machining feature, etc.

### Table 1: Standardized Check List

<table>
<thead>
<tr>
<th>Product Data Name</th>
<th>Material name / ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Data ID</td>
<td>Flow material dimension</td>
</tr>
<tr>
<td>Machine used</td>
<td>CAM operator ID</td>
</tr>
<tr>
<td>Jig &amp; Fixture used</td>
<td>CAM operator Name</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Machining process A</th>
<th>Machining process B</th>
<th>…</th>
<th>Machining process n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machining type</td>
<td>Machining type</td>
<td></td>
<td>Machining type</td>
</tr>
<tr>
<td>(milling, drilling, tapping)</td>
<td>(milling, drilling, tapping)</td>
<td></td>
<td>(milling, drilling, tapping)</td>
</tr>
<tr>
<td>Purpose of machining</td>
<td>Purpose of machining</td>
<td></td>
<td>Purpose of machining</td>
</tr>
<tr>
<td>(rough, finish, semi-finish)</td>
<td>(rough, finish, semi-finish)</td>
<td></td>
<td>(rough, finish, semi-finish)</td>
</tr>
<tr>
<td>Machining feature</td>
<td>Machining feature</td>
<td></td>
<td>Machining feature</td>
</tr>
<tr>
<td>Tools used</td>
<td>Tools used</td>
<td></td>
<td>Tools used</td>
</tr>
<tr>
<td>Cutting speed</td>
<td>Cutting speed</td>
<td></td>
<td>Cutting speed</td>
</tr>
<tr>
<td>Spindle speed</td>
<td>Spindle speed</td>
<td></td>
<td>Spindle speed</td>
</tr>
<tr>
<td>Feed rate</td>
<td>Feed rate</td>
<td></td>
<td>Feed rate</td>
</tr>
<tr>
<td>Feed Speed</td>
<td>Feed Speed</td>
<td></td>
<td>Feed Speed</td>
</tr>
<tr>
<td>Depth of cut (axial &amp; radial)</td>
<td>Depth of cut (axial &amp; radial)</td>
<td></td>
<td>Depth of cut (axial &amp; radial)</td>
</tr>
</tbody>
</table>

Figure 2: System Architecture
Each item will be assessed and interacted with other aspect such as assessment concerns (availability, production efficiency, cost, etc.). Each interaction will be associated with other aspects such as reasons, targets, to come up with the recommended action as the result. And if the recommended action is to send the product data back to CAM operation phase, all connections and interactions will also be enclosed. The assessed item will be the starting point for CAM operator to improve or reproduce product data.

3.2 System Architecture

Concerning the detail architectural scheme which illustrates the working method of the proposed system, as can be seen in Fig. 2, by means of graphical user interface (GUI) system, CNC operator interacts with the system. The structure of GUI system is developed based on flow of thinking of CNC operator. This is aimed to minimize the gap of understanding between existing practical activities and human computer interaction aspect. The check list is assessed by CNC operator in the working environment of the GUI system.

In depth, the interaction involves their way of thinking when making justification on the checked items based on all official rules, constraints, targets, etc. Meanwhile, CNC operators can also reuse the existing knowledge stored on knowledge database. This human computer interaction will come up with recommended actions as the result as well as its reasons on why the particular actions are recommended. In addition, the recommended action could be to pass the product data back to CAM operation phase.

Next approach is to capture the knowledge of above activities initiated by extracting the results or final actions as well as all correlated aspects from all domains. Afterwards, the results together with correlated aspects from all domains are summarized and then to be aggregated during knowledge aggregation phase. Processes of knowledge aggregation, knowledge arrangement and knowledge management are significantly related with ontological aspect and database modeling which are not yet described broadly on this paper.

Since the knowledge has been captured and managed, it can be used to enrich and to enhance other database system. In addition, the stored knowledge can be retrieved by associated agents for improving their performances.

3.3 Knowledge elements

Definitely, items on the check list are also aimed for coping with the diversity of knowledge which is certainly considered as a very important issue in knowledge-based system development. Generally speaking, there are two kinds of knowledge are identified: explicit knowledge and implicit knowledge. The first is associated with establish a modeling procedure, then become basic consideration. Since all aspects can be defined and correlated to each other, intelligence of human can be correspondingly related with the dynamic model, which is the supervisory control model. The decision making methods can be elaborated into two types: logical decision making and rule based decision making, which in sense of common practices are correlated to each other. Way of thinking which is closely related with human preferences according to their subjective perception or belief should be in line and in harmony with the rules, specific targets, constraints, etc.

3.4 Flow of thinking and domains interaction

Next consideration is about how to arrange everything within such standardized flow of thinking. To cope with this, probably the most intuitive idea would be to visit experts and gather rules by interviewing them without any knowledge capturing methodology. In this case, some serious problems may arise because every process engineer may think in a different way. If there are several

<table>
<thead>
<tr>
<th>Knowledge Elements</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facts / Objects</td>
<td>Product data, Check List, Reasons, Tools used, Cutting speed, Spindle Speed, Feed Rate, Feed speed, Depth of Cut, Features, etc.</td>
</tr>
<tr>
<td>Relationship among facts</td>
<td>Process Flow, Technological contraints, etc.</td>
</tr>
<tr>
<td>Logical Decision Making</td>
<td>Way of Thinking</td>
</tr>
<tr>
<td>Rule-based Decision Making</td>
<td>Rules, Targets, etc.</td>
</tr>
</tbody>
</table>

The know-how is presented as a set of rules where groups of rules are developed for each particular task of process planning. Regarding the knowledge-based activities taking place along this proposed system, the coming up challenge is how to correlate this issue with the assessment flow which is initiated and based on check list items in correlation with other aspects, i.e. assessment approach, rules, target & constraints of the production, potential actions as well as its reasons why selected or eliminated, etc.

Respectively, all aspects as well as the correlating methods should be reflected into knowledge-based point of view. And as the result, it is necessary to define everything to be reflected into particular knowledge elements. A modeling procedure, so called three-phase modeling framework [8], then become basic consideration. It consists of three sub-models: the object model, the functional model, and the dynamic model. In accordance, four types of knowledge elements, as described in Table 2, are identified as well as its coverage aspects.

The idea is to define all related aspects as a fact or object, and then arrange all relationship among them. Since all aspects can be defined and correlated to each other, intelligence of human can be correspondingly correlated with the system by including decision making aspects of associated agents. Decision making considerably has to do with the dynamic model, which is the supervisory control model. The decision making methods can be elaborated into two types: logical decision making and rule based decision making, which in sense of common practices are correlated to each other. Way of thinking which is closely related with human preferences according to their subjective perception or believe should be in line and in harmony with the rules, specific targets, constraints, etc.
types of flow which are different to each other, all cannot belong to the same knowledge base because they might assume implicit situation and different contexts. Consequently it is important to formalize a standardized flow of thinking, which is depicted in Fig. 3.

Assessment is initiated by interpreting all facts on the checked items as well as the relationship among all. Afterwards, common assessment is about whether materials and equipments used are available or not. Up to this step, in order to support the interpretation, CNC operator can access data and information about current status of equipments/tools in equipments/facilities database. Next, after the concern of equipments/facilities availability, CNC operators start assessing the product data according to the assessment concerns. Typical assessment concerns applied on this proposed system are cost, production efficiency, manufacturability and quality. CNC operators should assess the items with respect to assessment concerns.

In the meantime, the assessment concerns should be explored further so that these can be correlated with the reasons which fairly elaborate the concerns. For example, CNC operator may judge the performance of cutting tools based on its current outlook, and correlated with the concern of production efficiency, manufacturability, and quality of the end product coming out from machining process using assessed tool. Meanwhile, the reason of tool outlook is elaborated into more detail so that it can be understood as, for example, prediction of tool wear, or based on looking at tool color, etc.

Potential actions are then to be elaborated broadly by CNC operators. These could be some possible actions are coming into CNC operator mind. Each will sometimes have consequences on other item or fact. During this phase, self improvement method can be done by taking a look at past processes stored on the knowledge storage. Process on assessing the recommended action will end up at knowledge aggregation phase at which particular action has been selected over the others.

Figure 4 illustrates more detail example of domains interaction which is taking place at the phase of product data assessment (Fig. 1b) by means of the knowledge based system. The example is about the decision to use other tool due to unavailability concern. There are one main action and one secondary action taken into account. Since particular constraint of due date is to be taken into consideration, and since the other same tools (#ID09) are occupied by other machining operation, the main action taken is to change with another tool (#ID08). The secondary action which is the consequence of the main action is to adjust related machining parameters. In this
example, the following consequence is to increase cutting speed since supposedly tool #ID08 has better quality. All lines and arrows within Fig. 4 are representing correlation among corresponding aspects. Therefore, all aspects connected with those lines and arrows will be then aggregated together with all connecting lines and arrows. Further, all detail of aspects are described in particular description and as far as possible are described into numbers or levels. This way of description will be useful for the following processes which are closely related with ontological approach and database modeling. At this stage, rules then should be determined, and added into corresponding aspects. In this case, classes can be represented by interpreting further all facts, for example check list items, concerns of assessment, list of actions, list of reasons, list of equipments and tools, etc. Meanwhile, properties can be explored by interpreting all lines and arrows that connect all associated facts. Generally speaking, aggregation phase is aimed to set up classes and properties to be proceeded further by means of ontological approach and database modeling approach.

4. Future works and conclusions

Indeed, it is a big issue to construct a knowledge-based system for integrating CAM and CNC operations, which enables capturing, management, sharing, and maintenance of knowledge and experience of engineers. Although there have been many prior studies on knowledge-based system for supporting manufacturing process, research that focuses on capturing, managing and sharing the know-how of CNC operator for integrating CAM-CNC operation is rare.

In this paper, the three-phase modeling method is used to develop the definition of the knowledge elements. Four knowledge elements are defined: facts/objects, relationship among objects, logical decision making and rule based decision making. The existing of knowledge element definition is aimed to map everything within the system. Afterwards, all activity domains are interacting to each other based on flow thinking which is supposed to be standardized. As interaction among activity domains has already come up with the result, all correlated aspects are then aggregated. The result of aggregation is then used to construct the ontological scheme. This is important to be done since knowledge management, sharing and reuse will be closely related with ontological approach.

As for the future works, significant effort will be carried out to define the interacting aspects in domains interaction into more detail. More detail can be completed more accurate the result of aggregation. Another important concern should be put on conflicting potential actions that are possibly considered by CNC operator at the same time. Supposedly the best actions should be made. In that sense, certain decision making method should be properly added into the system. These are aimed to establish the fundamental framework before going through realizing the ontological structure so that all can be realized as standardized model useful for many cases in manufacturing enterprise.

Further, it is also essential to develop expert system so that the captured knowledge can be useful for associated agents for improving their performance. It should be able to bring the way of thinking of CNC operators into CAM operators mind, especially aimed for avoiding similar inaccurate items that have been adjusted or modified by CNC operator during previous project. As for a brief picture of the represented knowledge, when CAM operator is about to select suitable cutting tool, it can represented as particular range of numbers regarding combination among cutting speed, feed rate, and spindle speed for each possible tool. The range of each combined parameter keeps changing depending on current condition in shop-floor. Method on how to handle captured data and knowledge will be assessed further. Consequently, the detail of interacting domains and knowledge aggregation play significant role.

Regarding following works on database modeling, as the knowledge artifacts are properly aggregated, all should be able to be completely delivered into database modeling approach. As the database model is established, the expert system is hoped to be able to be developed further.

References