Robotics and Computer-Integrated Manufacturing 26 (2010) 583–595

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Full length Article

Integration of product design, process planning, scheduling, and FMS control using XML data representation

Dušan N Šormaz [a,*], Jaikumar Arumugam [a,1], Ramachandra S Harihara [b], Chintankumar Patel [c], Narender Neerukonda [d]

[a] Department of Industrial and Systems Engineering, Ohio University, Athens, OH 45701, USA
[b] PS&SD Department, Lexmark International Inc., Lexington, KY 40550, USA
[c] Department of Re-engineering, American Express Company, Weston, FL 33331, USA
[d] Department of Professional Services, Compuware Corporation, Independence, OH 44131, USA

ARTICLE INFO

Article history:
Received 2 December 2009
Received in revised form
18 July 2010
Accepted 26 July 2010

Keywords:
CAPP
Process planning
Manufacturing integration
Process plan representation
XML

ABSTRACT

An efficient model for communications between CAD, CAPP, and CAM applications in distributed manufacturing planning environment has been seen as key ingredient for CIM. Integration of design model with process and scheduling information in real-time is necessary in order to increase product quality, reduce the cost, and shorten the product manufacturing cycle. This paper describes an approach to integrate key product realization activities using neutral data representation. The representation is based on established standards for product data exchange and serves as a prototype implementation of these standards. The product and process models are based on object-oriented representation of geometry, features, and resulting manufacturing processes. Relationships between objects are explicitly represented in the model (for example, feature precedence relations, process sequences, etc.). The product model is developed using XML-based representation for product data required for process planning and the process model also uses XML representation of data required for scheduling and FMS control. The procedures for writing and parsing XML representations have been developed in object-oriented approach, in such a way that each object from object-oriented model is responsible for storing its own data into XML format. Similar approach is adopted for reading and parsing of the XML model. Parsing is performed by a stack of XML handlers, each corresponding to a particular object in XML hierarchical model. This approach allows for very flexible representation, in such a way that only a portion of the model (for example, only feature data, or only the part of process plan for a single machine) may be stored and successfully parsed into another application. This is very useful approach for direct distributed applications, in which data are passed in the form of XML streams to allow real-time on-line communication. The feasibility of the proposed model is verified in a couple of scenarios for distributed manufacturing planning that involves feature mapping from CAD file, process selection for several part designs integrated with scheduling and simulation of the FMS model using alternative routings.

1. Introduction

Computer Integrated Manufacturing (CIM) is still moving target in industrial and manufacturing engineering research and applications. There are numerous reports outlining individual islands of automation within the CIM model, with a significant effort in research papers being focused on a particular task, and much less effort devoted to integration of these manufacturing engineering and planning tasks. Integration involves the transfer of data between applications, but also should focus on data and model integrity, distributed processing of the data, incorporation of knowledge into the planning tasks, and so on. Computer aided process planning (CAPP) is rightly seen as an integration fabric for CIM with its relations to design (CAD), manufacturing (CAM), scheduling, and control tasks. By virtue of being an integrator between CAD, CAM, and scheduling/control, process planning involves decision making process on various levels of details with the final goal of generating feasible and/or optimal process plan. The need for integration requires that such model is transparent between these tasks and that it is easily saved or transferred.

This paper proposes such neutral data model in the form of XML model and describes its details and application in manufacturing process planning. The paper is organized as follows.

* Corresponding author. Tel.: +1 740 593 1545; +1 740 593 0778.
E-mail address: sormaz@ohio.edu (D.N. Šormaz).
[1] (Now with GE Energy, India)

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doi:10.1016/j.rcim.2010.07.014

Section 2 describes previous work in process plan representation and modeling. Section 3 describes process planning representation object model (PPRM), which includes major entities and relations between them. Section 4 explains process planning XML representation that is built for the PPRM object model and describes methods for writing data in XML format and parsing XML streams into object model. Section 5 explains a few scenarios of integration between feature mapping, process selection, scheduling, and FMS control using data in XML format and describes a case studies that were carried out to verify the approach. The paper ends with conclusions and the list of references.

2. Previous work

Data and knowledge representation in process planning have received significant interest in research. An early work on a language for process specification (ALPS) [1] proposed a graphical representation for manufacturing processes and means for specifying serial, parallel, and concurrent tasks. Since then, several papers addressed knowledge representation, for example, using frames and rules [2] or an object-oriented data model [3]. International Standard for the Exchange of Product Model Data (STEP) has been developed to enable data transfer between applications that includes process data [4]. Recent results are in generation of the Process Specification Language (PSL) [5] as a neutral format for the specification of process representation and exchange of different ontologies or semantics between various domains. Development of process planning specific, NC data within STEP standard has been described in [6]. Work on XML [7], as a very flexible language that transfers both data and their description (metadata) prompted its widespread use in many research efforts. Lubell et al. [8] discusses similarities and differences between STEP and XML and proposes their convergence.

Recent work has been in applying process representation to implement various systems. Several papers propose agent-based approach in modeling and developing coordinated product development [9] and in intelligent manufacturing [10] or utilize web-based approach [11]. The data representation in these approaches is usually based on the XML language. Cheung et al. [12] discuss a framework for capturing organizational knowledge in XML. The framework is implemented in collaborative product development and manufacturing system using ontology-based knowledge approach. CNC system TurnSTEP for turning operations based on STEP-NC data model is described in [13]. The system uses CAD information in STEP format and then allows a programmer to interactively specify details of stock, feature definitions, and process plan and generates XML file with program output. Siller et al. [14] describes the workflow model for process planning activities in context of CAD/CAM and PLM tools, while Weilguny and Gerhard [15] integrate CAD and CAM through an XML-based feature model which transfer product design data into CAPP and CAM applications.

3. Process planning representation and modeling

Manufacturing planning object model developed in this work is based on process planning object model proposed in [3], which described a data model for representation of process plans based on the different activities involved in manufacturing. A process planning representation model facilitates the development of algorithms for manufacturing problems like sequencing, scheduling, etc. by reducing the over-all algorithm development time. The model accommodates a variety of data that may be needed in manufacturing planning algorithms. Components of the model are manufacturing planning object model, feature object model, and process object model and they are described in this section.

3.1. Manufacturing planning object model

Manufacturing planning object model is shown in Fig. 1. The model is based on analysis of product and process design entities and includes hierarchical representation of manufacturing activities, that has manufacturing processes as its leaves, collection of manufacturing features and corresponding manufacturing processes, and a collection of machines used in the manufacturing system.

A manufacturing activity represents the core of the model. Any activity that contributes to the manufacturing of a part is called a manufacturing activity. A manufacturing activity has attributes like manufacturing cost, manufacturing time, member processes, etc. A manufacturing activity is subdivided as a part activity, a machine activity or a tool direction activity. A part activity describes the process plan for a part. There is an association relationship between part activity and part. Each part activity is associated with a part. A process plan for a part is a collection of the machine activities through which a part has to pass to be completely manufactured. The part in turn can have multiple alternative process plans (part activities). The machining process of a part on each machine in its process plan is represented by a machine activity. Each machine activity is associated with a machine object. There is an aggregation relationship between part activity and machine activity. Each part activity is a collection of machine activities. The part object has attributes like a collection of its alternative process plans, part material, features list, process list, etc. The machine object has attributes like machine name, number of units, usage frequency, etc. Each machine activity is a collection of tool direction activities. A tool direction activity holds directional information about a machining process. The member process attribute of manufacturing activity is used to store the aggregations of a manufacturing activity. Thus, the member process attribute of a part activity holds a collection of machine activities. The member process attribute of a machine activity holds a collection of tool direction activities. The representation model for the cellular manufacturing shown in Fig. 2 is built on the basis of the process plan representation model and serves as its extension for cell formation.

The core of the cellular manufacturing model is the manufacturing system. A manufacturing system is a place where parts are manufactured on machines. The main task of cell formation is the partition of the parts in the system into part families and machines into machine cells to reduce intercellular traffic. The objective is to find a partition for machines into machine cells and parts into part families in such a way as to minimize intercellular traffic.

3.2. Feature object model

The feature object model represents a hierarchical representation of various machining features with inheritance relations within it. The model is shown in Fig. 3. The major class is *MfgFeature* that abstracts all common properties for all features. Properties at this level include feature name, containing part, tolerance data, list of alternative processes, and precedence relations. *MfgFeature* class is extended into several subclasses that correspond to machining feature types found in mechanical prismatic parts (such as *Hole*, *Slot*, and *Pocket*). These classes model properties of particular feature type and include different