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Manufacturing planning and predictive process model integration using software agents

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Abstract

Intelligent agents provide a means to integrate various manufacturing software applications. The agents are typically executed in a computer-based collaborative environment, referred to as a multi-agent system. The National Institute of Standards and Technology (NIST) has developed a prototype multi-agent system supporting the integration of manufacturing planning, predictive machining models, and manufacturing control. The agents within this platform have access to a knowledge base, a manufacturing resource database, a numerical control programming system, a mathematical equation solving system, and a computer-aided design system. Intelligence has been implemented within the agents in rules that are used for process planning, service selection, and job execution. The primary purposes for developing such a platform are to support the integration of predictive models, process planning, and shop floor machining activities and to demonstrate an integration framework to enable the use of machining process knowledge with higher-level manufacturing applications.
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Keywords: Intelligent agents; Manufacturing planning; Machine control; Multi-agent system; Systems integration

1. Introduction

Current computer-aided design (CAD) and computer-aided manufacturing (CAM) systems are typically operated in a stand-alone mode. According to a Daratech survey [1], the CAD/CAM industry is a $5.3 billion (USD) industry worldwide. Based on industrial needs, it is necessary to integrate other software systems, tools, existing databases, or knowledge bases with CAD/CAM systems. For example, most commercially available CAD/CAM systems do not have embedded databases for attributes like cutting parameters. Manufacturing engineers must look up the recommended cutting parameters in handbooks or from sources provided by vendors. This information may be outdated, not relevant for particular situations, or overly conservative. Scientifically developed mathematical models of cutting processes have been developed, such as models for predicting machining stability and estimating cutting tool life [2]. These process models and the machining process knowledge they contain must be made available to design and manufacturing engineers within the appropriate CAD/CAM systems early in the product lifecycle to have the largest impact. The use of sub-optimal machining process parameters has a significant impact on manufacturing costs, causing longer machining times, shortened tool life, and reduced part accuracy.

Some fundamental problems that cause the manufacturing inefficiency include:

1. Interoperability among heterogeneous software systems and tools is generally not available. The design, manufacturing, and supply chain software systems are not interoperable across software ownership boundaries.
2. Computing environments are usually distributed, such as those for design knowledge bases, material databases, resource databases, manufacturing process modeling systems, and process knowledge bases. Additionally, these systems are not linked with CAD/CAM systems.
3. The use of sub-optimal process parameters increases the manufacturing cost because of increased tool wear or under-utilized tools and machines. Optimal cutting parameters are not always available to manufacturing engineers because the Numerical Control (NC) programming systems and physics-based cutting process models are not linked with each other.

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4. Web-based collaboration between the process planning activity and the process parameter optimization activity is currently not available. This impedes collaborative activities in a distributed computing environment within a company's engineering department.

To alleviate these problems, industry requires technologies that can enable interoperability among software systems in a distributed computing environment and integrate various capabilities into the user's software systems. Some specific solutions are as follows:

1. Mechanisms for software components to communicate with each other across computer networks with as few changes as possible to the original software.
2. Processes (software behavior) that can be changed and services that can be added without changing existing codes.
3. Software capabilities that are defined and registered in a database where others can access.
4. Representation of the domain knowledge and objects shared by different software systems is open and well defined.
5. Web-accessibility built into agents so that they can be remotely controlled and monitored. The agents should enable collaborative work in process planning and design.

The objective of the work described in this paper is to use autonomous agents [3], to integrate manufacturing applications, including manufacturing process planning and machine control, and supporting software, such as knowledge base systems, database management systems, and mathematical modeling software tools. The capability to support the manufacturing planning and control functions is embedded in software agents. The functions in the manufacturing software become the agents' capabilities. Agents communicate with each other using an augmented Agent Communication Language (ACL) [4] by sending requests and responses in a standard format with necessary information. The message content format for our applications is not supported by the current ACL specification. Message content format and interaction protocols are defined as an extension of ACL. The purpose is to integrate commercial software systems across system boundaries. Specifically, we use the scenario of process planning and NC machine control as an example to illustrate a prototype integration framework based on machining process models, an agent knowledge base, a manufacturing resource database, and interfaces to both the process planning application and the machine controller.

An agent-based approach is used to take advantage of the flexibility offered when needing to integrate additional software tools or to add additional software agent functionality. When a software agent needs to behave differently, only the agent's knowledge representation must be changed. The code needs little or no changes. Standards published by the Foundation of Intelligent Physical Agents (FIPA) [5] are available for multi-agent system implementations, and have been adopted in this work.

The rest of this paper is organized as follows. Section 2 of this paper provides a survey of the current state of intelligent agents in design and manufacturing. Section 3 describes the proposed integration framework for process planning and machine control for automated manufacturing. Section 4 presents the implementation of the integration framework using available tools. Section 5 presents some conclusions from this work, and is followed by the disclaimer and references.

2. An overview of multi-agent systems in manufacturing applications

This section provides a brief review of our previous work and the related literature in this area. In prior work [6], an architecture for integrated knowledge-based preliminary process planning functional components has been developed. The architecture consists of an inference engine, a product database, a manufacturing knowledge base, and a resource database. The inference engine is used to select preliminary manufacturing processes and resources, and to estimate manufacturing cost/time based on manufacturing knowledge according to product information. The product database stores product information pertinent to preliminary process planning. The manufacturing knowledge base has process planning rules. The manufacturing resource database stores descriptions of tools, machines, labor skills, and computer software capabilities. The semantics for information exchange used by agents between design and process planning is based on an integrated design and manufacturing object model, described in [7,8].

Potential applications of multi-agent systems in concurrent design and manufacturing have been described in [9, 10], with examples given in the areas of product design, manufacturing planning, shop-floor control, and manufacturing equipment control. A design and manufacturing optimization environment has been developed in [11] using a web- and agent-based framework. Multi-agent systems have also been applied to the area of shop-floor scheduling, to address scheduling of machine tools based on job requirements [12]. The agents negotiate with each other to find the best utilization of resources, including cutting tools, machine tools, and fixtures.

The lack of an integration scheme for the integration of design and manufacturing applications costs industry a great deal in using manufacturing software tools. The tools are typically isolated and cannot interoperate across system boundaries. Multi-agent technology provides software developers with methods and tools to link various engineering software tools. This technology can enable the flexible integration that is needed by industry.