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COLLABORATATIVE SOFTWARE AGENTS IN STEEL INDUSTRY

Heli Helaakoski[1], Shaw C. Feng, Kevin K. Jurrens[2], Kaija Ojala[3], and Janne Kipinä[4]
[1]*VTT Electronics, Rantakatu 5, FIN-92100 Raahe, Finland*
[2]*Manufacturing Engineering Laboratory, NIST, Gaithersburg, Maryland 20899, U.S.A.*
[3]*University of Oulu, Rantakatu 5, FIN-92100 Raahe, Finland*
[4]*Oulu Polytechnic, Raahe Institute of Computer Engineering and Business, Rantakatu 5, FIN-92100 Raahe, Finland*

Abstract

In recent years there has been increasing work where software agents have been used in manufacturing enterprises. Improving the information flow within the company and between the collaborative companies is very important to increase the competitive position and profitability. Networked manufacturing enterprises are now moving towards open information exchange for integrating their activities with those of their suppliers, customers, and partners within wide supply chain networks. In manufacturing processes, agents can support the integration of predictive models, process planning, and shop floor machining activities. Software agents can also be used to integrate manufacturing applications with the business applications. This paper presents how agents can be exploited for manufacturing enterprise integration and supply chain management to meet such requirements in steel and its related industries.

Keywords

Distributed manufacturing systems, supply chain management, intelligent agents, multi-agent systems, agent-mediated workflow and supply chain management.

1. Introduction

The first business-to-business (B2B) systems were developed with the idea of transmitting electronic messages representing such documents as invitation tenders and purchase orders about 25 years ago. These message transfer systems were based on B2B protocol standards such as Electronic Data Interchange (EDI) [1]. However, these systems have become legacies and are very inflexible and expensive to use especially for small- and medium-size companies. Current Internet technologies are expected to ease these restrictions by being more efficient and economical. Through the use of Internet technologies, the traditional B2B systems have extended to business networks where several companies are collaborating via electronic messages.

Business-networked systems typically consist of several repeated chains of events like the requisition of resources, a request for quotes from candidate business entities, vendor selection, order enactment and delivery, relationship management among businesses, and product life cycle management. These systems can be used to support the functions of several business networks, such as a strategic sourcing network, an electronic procurement network, a network for virtual enterprise, a network for product design, manufacturing, inventory, and delivery management, a network of electronic marketplaces, a network for workflow/supply-chain management, and a network for supplier relationship management [2]. These networks are based on the Internet. Recently, many researchers have studied the use of software agents that are autonomous and intelligent for easing this complex environment of business networks in electronic commerce.

While business networks have the focus on information transmission between companies, the information flow within the companies is equally important. Improving each company's own supply chain management is a key mechanism for increasing competitive position and profitability. Agent-based technology provides a way to design and implement systems that integrate legacy systems into business networks. Additionally, software agents have been increasingly used in the product and process development in industry over the past years due to the rapid evolvement of the Internet technology. Agents with access to product design and process planning knowledge bases can aide engineers to reduce product development costs. Agents are also used in the integration of design, process planning, machine control, and shop-floor job execution in the mechanical part manufacturing industry.

In this paper, we present how a community of agents can make decisions and carry out tasks within a manufacturing company or across companies in a manufacturing supply chain. We have proposed a company network architecture that is connected to enterprises' legacy systems by using agents. The business network of agents is being developed by the SteelNet project at VTT (Technical Research Centre of Finland). The aim of the SteelNet project is to research the use of agents in industrial business networks by developing an agent-based prototype. Better information control by the means of agents strengthens the competitiveness of the SteelNet company network.

A product design and manufacturing network of agents is being developed by the Predictive Process Engineering Program of the Manufacturing Engineering Laboratory at the National Institute of Standards and Technology (NIST), a federal agency within the U.S. Department of Commerce. Within the NIST research activity, agent communication is performed in a prototype multi-agent platform to demonstrate sharing of manufacturing knowledge and process data throughout the product lifecycle. Due to the use of common development and agent communication methodologies, a collaboration has been formed to take advantage of potential overlapping objectives. The goal of the collaboration is to further develop the demonstration capabilities so that agents from both the business and engineering networks are able to exchange messages and share knowledge with each other. Our system provides the support for a variety of transactions among the business entities and among engineering activities within a company.

This paper is organized as follows: Section 2 describes the business case and the basic functionalities of an agent-oriented system for managing business networks. Section 3 describes a framework for integrating predictive process models, process planning systems, design systems, and machine tool control. Section 4 describes related work. Section 5 concludes the current work and outlines our future plans. Section 6 has acknowledgements. Section 7 contains a disclaimer. All the references are in the last section of the paper.

2. An Agent-oriented Business-Networked System for the Steel Industry

The SteelNet business network consists of several collaborating companies in the steel products industry. Within the business network, companies work together as a distributed supply chain, while each of these companies has its own field of expertise like bending, flame cutting, and welding. Besides this business network each company has its own customers and partners, therefore each company must have equal rights and responsibilities in the SteelNet system. In other words, each company independently requests for quotes or makes orders unlike traditional subcontractor systems.

In the SteelNet system, agents represent major functionalities of a company. Figure 1 shows the usual operations in manufacturing companies. Most communication among human beings and some decision-making activities will be substituted by agents in the SteelNet system. The agents are able to communicate and collaborate both within the company and with agents from other companies via the Internet. This enables the seamless information flow through all operations in the company and also through the entire business network.

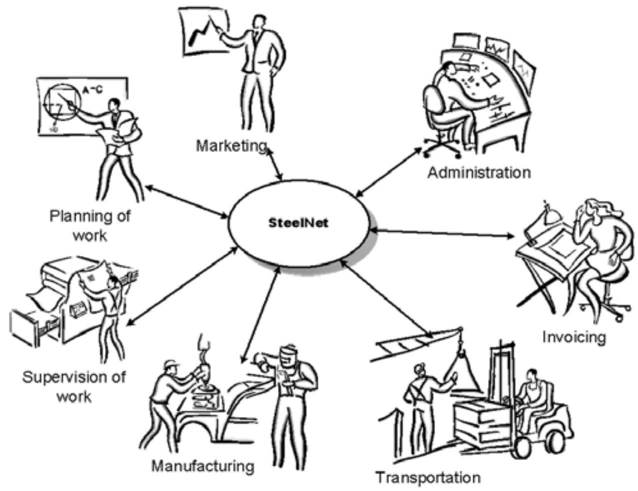

Figure 1 The SteelNet business network.

Figure 2 shows a physical view of the SteelNet architecture. On the left side is a simplified view of a company network consisting of many workstations and one agent container server in a local area network. The company LAN (Local Area Network) is connected to the Internet through a firewall. In practice all companies have different network structures, since the companies vary from small engineering workshops to big corporations with hundreds of personal computers, servers and other systems networked together across far-reaching geographical locations. However, the basic principle is that the agent container server is accessible from workstations and that there is a firewall protecting the company network. On the right side is the service provider with the main agent container server connected to the Internet and database server connected through a local connection. In practice there is a firewall protecting the servers in the service provider side also, but it has been omitted in the picture since it does not limit the traffic required by the SteelNet application.

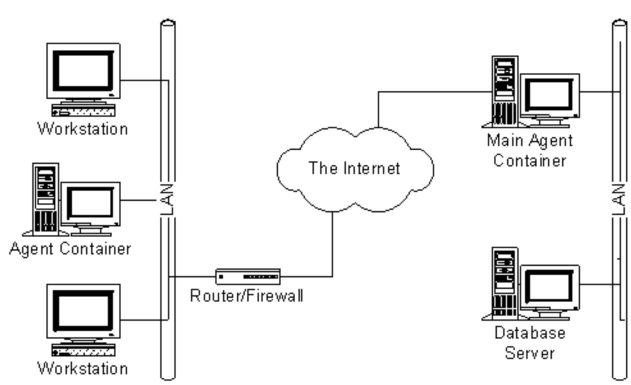

Figure 2 Physical view of the SteelNet architecture.

Figure 3 shows the logical architecture for SteelNet, again the left-hand side presenting one company in the business network and the right-hand side presenting a service provider. On the company side there are two general-purpose software modules, the Hypertext Transport

Protocol (HTTP) server/servlet container and the legacy systems proxy. By utilizing Java servlet technology and the servlet container any agent or other software module running in the agent container server can provide web-based user interfaces to users in the company local area network (LAN). For each task, for example manufacturing or sales, there is a separate agent and an accompanying interface to transfer data to the agent. Furthermore, the agent may register its user interface servlet to the servlet container. The agent can also provide a module to the legacy systems proxy to interact with legacy systems in the company network. The idea behind the accompanying common interface is that the agent is neutral to whether the data is fed by a user through web interface or by the legacy system proxy after extracting it from a legacy system.

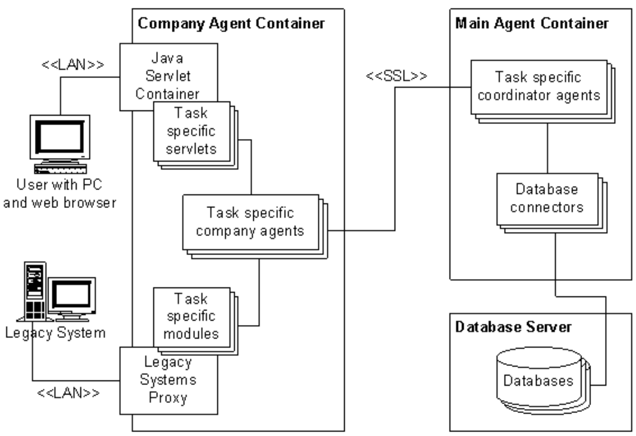

Figure 3 The logical view of the SteelNet architecture.

The service provider side contains coordinator agents for each task. Each coordinator agent acts as a bridge between task agents in different companies and also provides data storage for the agents. The use of coordinator agents makes the system somewhat centralized, but it has some very considerable advantages. Firstly, the data is readily available, and in obscure situations it is easier to inspect if the data has been changed and by whom. Secondly, direct communication between agents in companies is likely to be interfered with by a company firewall. In the main agent container, the same common interfaces are used in the company side to provide transparency to where the data is actually stored. The coordinator agents just obtain the data through the interface to some specific module, which then creates the actual database queries to the database server. Communication between the main agent container and agent containers located in companies is secured by using the Secure Socket Layer (SSL) connection.

In the future, the architecture will be enhanced to make it more affordable and decentralized. In large business networks, the main agent container may not be able to handle all of the processing loads caused by the vast amount incoming and outgoing data. Perhaps some hybrid solution would work in this kind of environment, so that instead of the single main container, there would be several, so-called, super-peers.

3. An Agent-based Process Integration Framework for Steel Part Manufacturing

A framework for integrating predictive process models, process planning systems, design systems, and machine tool control that enables the flexible integration of heterogeneous manufacturing applications has been developed by staff of the NIST Predictive Process Engineering (PPE) program. With an emphasis on information requirements for the integration of software and hardware systems for predictive process engineering, the framework includes the component architecture, interaction sequence model, message and communication format, agent platform, process knowledge, and supporting tools. The purpose is to describe agent behaviors, communication methods, and an agent system structure.

3.1 Component architecture

The component architecture describes the software components used in the agent-based integrated design, planning, and control system. Figure 4 shows the agents that are executed in the agent platform. The agents include a design agent, a group of process planning agents, a capability repository agent, and a manufacturing control agent. Humans interact with the agents through graphical user interfaces (GUI). The design agent communicates with a CAD system (Pro/Engineer Wildfire) to send and retrieve information about part design. With the CAD system, engineers define the shape and attribute information of a design of part components or an assembly.

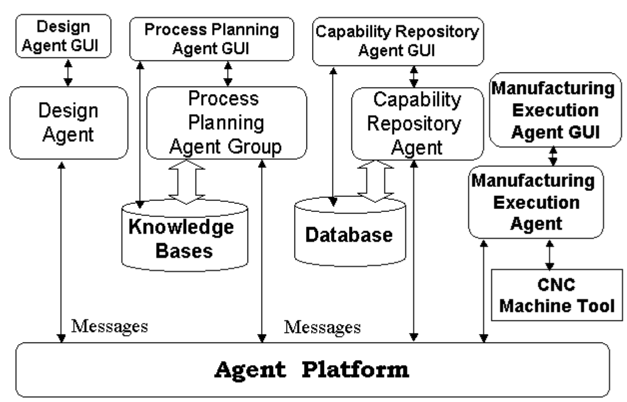

Figure 4 A multi-agent system architecture.

Figure 5 shows agents in the process planning agent group. The process planning agent communicates with a Computer-Aided Process Planning (CAPP) system and a CAM system to generate Numerical Control (NC) programs that are used to control Computer Numerically

Controlled (CNC) machine tools. CAPP software provides functions for selecting processes and resources and for generating process sequences. The NC software is used to create tool paths and NC programs for running computer numerically controlled machine tools. The agent sends and retrieves information about machining process planning to and from both CAPP and CAM systems. It also interacts with the Tool Material Selection Agent to select an appropriate cutting tool material. The tool material selection agent selects the cutting tool material based on workpiece material, tool life requirements, and desired cutting speed. Tool material selection rules are stored in a knowledge base, implemented using Java Expert System Shell (Jess) [3]. The material removal rate evaluation agent uses a mathematical model to calculate the maximum material removal rate based on the dynamics of the specific machine tool, the configuration of the cutting tool/tool holder/machine spindle, and factors in the machining process. The agent then calculates an optimal set of cutting parameters, including cutting speed, feed rate, and depth of cut, based on the specific conditions.

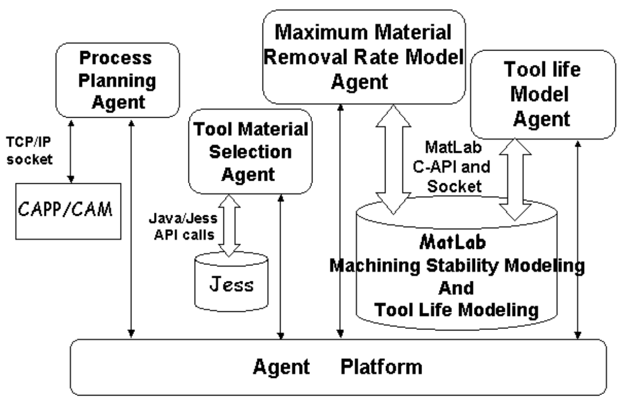

Figure 5 The process planning agent group.

Figure 6 shows that the capability repository agent operates on the agent platform and uses a database for storing and retrieving the capability information about each agent that provides services. Based on the Foundation for Intelligent Physical Agents (FIPA) specifications [4], the agent platform manages the agent activities.

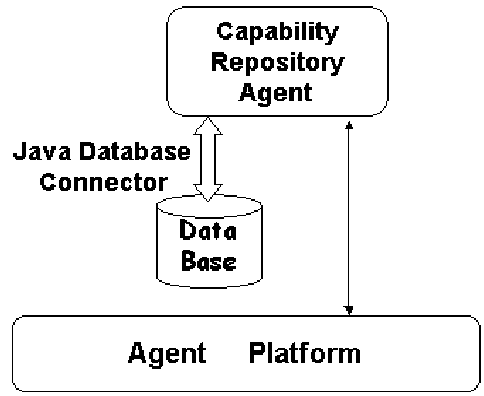

Figure 6 Capability repository agent.

3.2 Interaction model

The interaction model specifies the timing and sequence of function calls – the interactions among agents. Figure 7 shows interactions among agents for one of the scenarios used in the integration framework. All the agents, except the Process Planning and Capability Repository agents, must first register their capability in the database. From within the CAM system, the manufacturing engineer launches the Process Planning agent to determine and provide the optimal cutting parameters. Based on knowledge from the Capability Repository, the Process Planning agent obtains the tool material information by sending a request to the Tool Material Selection agent. With this information, the Process Planning agent then determines an optimal set of process parameters based on analysis from both the machining stability perspective (i.e., highest material removal rate while maintaining a stable cut) and the cutting tool life perspective (i.e., recommended material removal rate to achieve specified cutting tool wear rate and tool life). With the result, the NC program can therefore be completed within the CAM system.

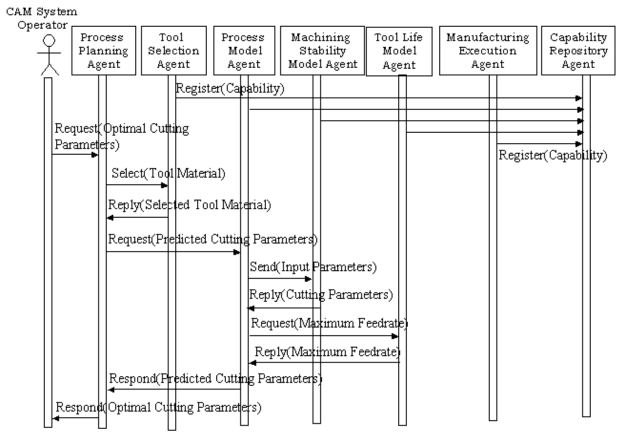

Figure 7 Agent interaction diagram

3.3 Message format

Agents communicate with each other by exchanging messages. A message has two sections: message header and message content (also known as message body).

The header contains the information regarding the sender, receiver(s), subject, date, time, and priority. There is also a slot that contains the agent identification (AID). Using the AID, the information about an agent, such as its name, can be retrieved from a repository or agent directory.

The message content contains information regarding the intent. There are two types of content: illocutionary and perlocutionary. The illocutionary message is used to inform other agents, such as registering an agent's capability. The perlocutionary message is used to request actions of other agents, such as a request for machining process optimization or a call for proposal. Message content has the following attributes: an action verb, an object, preconditions, and constraints. The action verb is used to indicate the type of action to be taken by the receiver, such as request, propose, and query. An object is the result or expectation. Examples of classes of objects can be found in [5]. Classes related to the milling process have been applied. Preconditions are the properties that the sender may supply. Constraints are limitations with which expected results should be constrained. They are specified to provide information to the receivers to produce valid results. Agents must have intelligence to process messages. A body of knowledge supports the intelligence of an agent.

3.4 Knowledge base

The source of agent intelligence is in the knowledge base. This knowledge base contains rules that govern the agent behaviors. An agent's knowledge includes how to inquire about the capability of other agents and how to perform special tasks. For example, special tasks may include functions such as tool material selection, machining stability analysis, or tool life evaluation. Basic rules for tool material evaluation can be commonly found in literature on process planning for metal cutting [6]. More specific and customized rules can be entered into the knowledge base. The rules are structured using propositional logic. The rules for both machining stability analysis and tool life evaluation are in mathematical form. The machining stability analysis is based on machining measurements and a machining chatter analysis and the tool life evaluation is based on the Taylor tool wear principle, both methods are documented in the literature [7]. These two mathematical models are implemented using available mathematical software tools.

3.5 Manufacturing resource database

The manufacturing resource database contains information about the equipment and tools used in the machining process, such as data and attributes for the machine tools, cutting tools, and fixtures. The structure of the database is relational, and the database is accessible by external programs via the Java database connector. In the database, a machine tool is defined by a set of attributes, such as the maximum power, the maximum cutting force in each axis, the maximum workspace dimensions, tool magazine information, the number of cutting axes, the maximum spindle speed, and available cutting tools. A cutting tool is defined by another set of attributes, such as tool identification, tool length, tool size, number of cutting edges, cutting angles on each edge, tool material, and tool overhang as mounted in its holder. Other resource information, such as for fixtures, workpiece materials, and operator skills can also be stored in the database. An object model on machining resource information can be found in [5].

4. Related work

Recently a number of research projects have been related to information systems of business networks. Different architectures and platforms have been proposed to support distributed operating over company boundaries.

The NIIIP (The National Industrial Information Infrastructure Protocols) [8] consortium was a team of organizations that entered into a cooperative development agreement with the U.S. Government. The main aim of this consortium was to develop inter-operation protocols for manufactures and their suppliers. NIIIP made it easier for engineering organizations to share technical product data over the Internet. They did this by building on the ISO 10303 (informally known as STEP) standard for product data exchange [9]. STEP provided common definitions for product data that can be read and written by many CAD/CAM/CAE and PDM systems [10].

The MetaMorph project at the University of Calgary developed a mediator-centric federation architecture for intelligent manufacturing [11]. In MetaMorph I, agents were used to represent manufacturing devices and products or parts to be fabricated, while mediators were used to coordinate the interactions among them. The follow-on research project, MetaMorph II aimed to integrate the manufacturing enterprise's activities with those of its suppliers, customers and partners into an open, distributed intelligent environment. For this purpose a hybrid agent-based architecture, combining the mediator and the autonomous agent approaches, was proposed [12].

DEDEMAS, GNOSIS-VF and PRODNET II are all Esprit projects founded by the European Union. The DEDEMAS (Decentralised Decision Making and Scheduling) approach provided a Mediator-based mechanism for decentralised decision making and scheduling covering both multi-site operations of one company and its chain of external suppliers [13]. The purpose of the Mediator is to extend and integrate the functionality and data of existing legacy systems. The GNOSIS-VF (The Virtual Factory) [14] concerned about development of the Virtual Factory Platform, i.e., information technology support for the Virtual Factory. The main objective was to design an organizationally distributed, web-based client-server architecture for the Virtual Factory and development of tools for the Virtual Factory Platform. The PRODNET II (Production Planning and Management in an Extended Enterprise) [15] project developed a reference architecture and an open platform to support industrial virtual enterprises with special focus on the needs of small- and medium-sized enterprises. The PRODNET infrastructure includes two main modules for each enterprise in the network: Internal Module representing the autonomous unit of a particular company and Cooperation Layer containing the functionalities for the inter-connection between the company and the whole net.

5. Conclusions and Future Work

The work of SteelNet continues with implementation of the first prototype with a web-based graphical user interface. This first prototype will be completed by the end of the year 2003. As a first test case, we will follow a distributed supply chain of three different companies that manufacture a heavy metal component. Furthermore, the first prototype serves as a test case for evaluating technical solutions and especially for the secure agent messaging through SSL in a real-business situation. After the first prototype is completed, the work will go on by embedding the agents into companies' own legacy systems.

A prototype agent-based integration framework to enable the use of machining process knowledge with higher-level manufacturing applications has been developed. Within this framework, data can be transmitted from a client agent to the appropriate service-providing agent(s). The intelligent agents can be used to optimize process performance through standard agent communication protocols and implement mathematical process models with specified goals and constraints. The process planning agent optimized the NC programs with regard to tool life and material removal rate using services provided by two additional agents. This multiagent system has demonstrated an approach for system interoperability. The agents communicate with each other using the FIPA standard message format and a common vocabulary. Further enhancements are expected to provide additional capabilities and to address additional scenarios. When the system is further expanded, the agents will also compete with each other for providing the best possible services.

Collaborative efforts between VTT and NIST will continue to advance the respective research objectives. It is expected that the collaborations and further development will lead to increased capability in the respective prototype and demonstration systems.

6. Acknowledgements

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7. Disclaimer

No approval or endorsement of any commercial products by the National Institute of Standards and Technology (NIST) is intended or implied. Certain commercial software and hardware systems are identified in this paper in order to facilitate understanding. Such identification does not imply that these systems are necessarily the best available for the purpose.

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