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Implementation of remote robot manufacturing over Internet

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Abstract

Remote manufacturing allows companies to dynamically establish manufacturing alliances by exploiting advantages of enabling information technologies. Product data management and information integration are two of the most important issues for success of remote manufacturing. In this paper, we studied the two issues by taking a case of a remote manufacturing implementation in a robot manufacturing company. An integrated product data model and the related configuration management methods are developed. Under a hybrid architecture of Web browser/server and client/server, an application system is presented to manipulate the product data and to carry out a variety of manufacturing functions. Finally, a CORBA standards-based integration framework is proposed to achieve interoperability among multiple data and application objects over the Internet and company Intranets. © 2001 Published by Elsevier Science B.V.

Keywords: Remote manufacturing; Product data model; Information integration; Configuration management

1. Introduction

Approaching the 21st century, manufacturing companies have been plagued by depletion of natural resources, diversified customer requirements, reduced product lifecycles and increased production complexity. Turbulent changes demand changing the traditional ways in which companies organize and carry out the manufacturing activities. Technology advances fuel the manufacturing philosophy shift. To gain collective competitive advantages in the changing markets, manufacturing companies are compelled to form various alliances, collaboratively providing customer-demanded products and services. Product manufacturing activities ranging through stages of the product lifecycle are carried out by a "virtual enterprise" consisting of cooperation members located in different regions. A virtual enterprise can easily gain and integrate more resources through internal integration and cooperation with other enterprises to provide quick response to customer expectations within a rapidly changing business environment [1].

Nowadays, it is very difficult to talk about virtual companies or alliances without mentioning the enabling information infrastructures built over the Internet. The rapid emergence of increasingly Internet-based services is greatly shaping manufacturing industries. Internet developments offer sophisticated communication and information transfer services supporting market exploration, electronic commerce transactions, collaborative manufacturing among geographically dispersed organizations. More importantly, Internet communication technologies break through barriers between customers and manufacturing companies,

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providing an effective mechanism to support development of customized products [2]. Increasing number of companies are exploiting the Internet business opportunities, which require easy access to multiple data sources while maintaining data integrity in the distributed heterogeneous environments. Remote manufacturing, also known as distributed manufacturing, is a specific form of virtual enterprises, which exploits the Internet technologies for information communication and function coordination among partners scattered over long distances.

Developing a comprehensive product data, model is recognized to be fundamentally critical to implementing remote manufacturing. Actually, product modeling is the indispensable key ingredient of most implementations of advanced manufacturing technologies, and many research efforts have been devoted in this area [3,4,5]. Product modeling can be viewed as representing product model information with appropriate data structures that are free of data or information inconsistency [6]. Instead of maintaining product databases within the company boundaries, Web technologies are increasingly used to facilitate exchanges of product data across the Internet [7,8]. In the remote design and manufacturing environments, it is of great significance to efficiently search for the necessary information from a multitude of dispersed databases. Recently, a constraint evolutionary algorithm was proposed for searching modules stored in multiple databases across different computer platforms [9].

Integrating multiple information sources in the distributed heterogeneous environments is another challenging task. Over the past two decades, much knowledge and practical expertise about information integration have been accumulated by research and applications of computer integrated manufacturing systems (CIMS) [10,11,12]. In general, CIM involves integration of multiple predetermined application systems and data sources distributed within company borders. In many CIM implementations, people can easily keep track of the information sources and control the developments of domain-specific application systems to be integrated. The top–down design methodology and client/server architectures are often adopted in implementation of these integrated systems. A number of reference architectures which support this top–down approach have been proposed, most notables amongst these are CIM–OSA, PERA, GRAI and ARIS [13]. In the case of remote manufacturing across different companies, it is much more difficult to integrate the dispersed information sources beyond company borders. System designers have no earlier knowledge of numbers and types of the data sources to be operated, and have no control of application systems that are to be added to and/or removed from the environments. Consequently, it is difficult to use top–down design methodology and client/server architectures for integrating the numerous applications and data sources in the remote manufacturing environments. The object-oriented design methodology and browser/server architectures tend to be more suitable for implementing these remote manufacturing systems. Object-oriented techniques provide a new way of thinking about problems through models organized around real-world concepts. The fundamental construct is the object in which data and associated operations that are normally performed on that data are encapsulated in a single entity. Therefore, instead of passing data to procedures and having these procedures operate on the data, the objects can be invoked to operate upon themselves [14].

Web-based applications are increasingly used by companies for communicating information with a great number of the distributed users. For instance, many companies develop Web-based systems to offer customer support service over the Internet [15]. However, the Web-based applications over the Internet result in new challenges, such as interoperability, security, data integrity and seamless access to multiple data sources. OGM's CORBA service specifications provide transaction management services, including remote database access, interoperability and distributed object transactions. CORBA compliant technologies enable a shift to distributed object-oriented computing. To support interoperability in a heterogeneous environment, the components of a system are normally defined as distributed objects and packaged as independent pieces of code that can be accessed by remote clients by method invocations [1]

In this paper, we address the remote manufacturing problems in a manufacturing company producing industrial robots. The production of robots is a very typical case of the remote manufacturing. As the company does not have all the required design and fabrication competencies, it tries to focus on the unique core competencies and know-hows, and to effectively explore the external resources. The company conducts only the tasks of its focused core competencies, and counts on numerous partners carrying out the remaining tasks. The company assembles the outsourced components and standard components into robots and delivers them to customers for on-site installations. Its customers, suppliers, design and fabrication partners are located throughout the world. In the past, business transactions, data distribution and coordination activities have been accomplished by dispatching technical and sales personnel, and using traditional communication means such as telephone, fax and post mails. To exploit the advantages of Internet, an integrated information application system is developed to support information transactions within the company and among the partners.

The rest of this paper is arranged as follows. In Section 2, we present the robot product data model developed to comprehensively capture and organize, in a unified framework, the product data required by various manufacturing functions. Then, we discuss the configuration management process that dynamically manipulates the product data model. Configuration management presents holistic views of the robot products, by both describing the relationships among the robot variants and depicting the configuration transformations through the successive stages of product lifecycles. In Section 3, we describe the architecture of the application system that carries out a variety of remote manufacturing functions with access to the product data. Further, we propose an integration framework based on CORBA standards to achieve interoperability among multiple data and application objects in the heterogeneous environments. Finally, Section 4 concludes this paper.

2. Robot product data management

The essence of remote manufacturing is the tightly coordinated cooperation among partners forming a virtual company, making the best use of the various necessary manufacturing resources. The participants of a virtual company in the remote manufacturing environment are independent, autonomous organizations seeking self-interest optimization at cost of certain internal resources. In most cases of manufacturing alliances, it is very difficult for all the participants to play equal roles. Quite often, companies with core competencies will play dominant roles in the manufacturing processes. And, other companies just reactively respond to requests and assignments from the dominant companies. In the whole product lifecycles, there are four types of participants, namely the customers, the dominant companies, the satellite partners, and the suppliers (as shown in Fig. 1). Customers are organizations that initiate manufacturing requirements and finally own the end products to be manufactured. Dominant companies are those that directly contract with customers, and take full responsibility for the end product deliveries and maintenance processes. Dominant companies initiate and coordinate the cooperation processes by outsourcing and subcontracting tasks to other participants (ordinary partners). Satellite partners are those that perform the outsourced and subcontracted tasks from dominant companies. Satellite partners generally do not account for the whole manufacturing processes, and only carry out a part of the design and fabrication activities. The partners may be more specifically categorized into design partners, fabrication partners, and sometimes including the distribution partners. Suppliers are organizations that provide on-shelf raw materials, standard parts and components.

In today's competitive markets, diversified customer requirements for specifically customized products make robot manufacturing extremely complex. Robots consist of a wide variety of mechanical and electronic components that are frequently required to be changed to meet specific end-uses. The frequent structural modifications brought into existence by customer requirements exert tremendous impacts on design and fabrication processes, the supply process and the service process. Apparently, managing product data and the relevant changes is the basic necessity for optimization of the global performance of a virtual company. In the remote manufacturing environments, the data sources concerned have following characteristics.

1. As the manufacturing activities are carried out by many organizations, the data sources are geographically distributed over a large area or even throughout the world.
2. Information heterogeneity is created across the numerous data sources, including part designs,

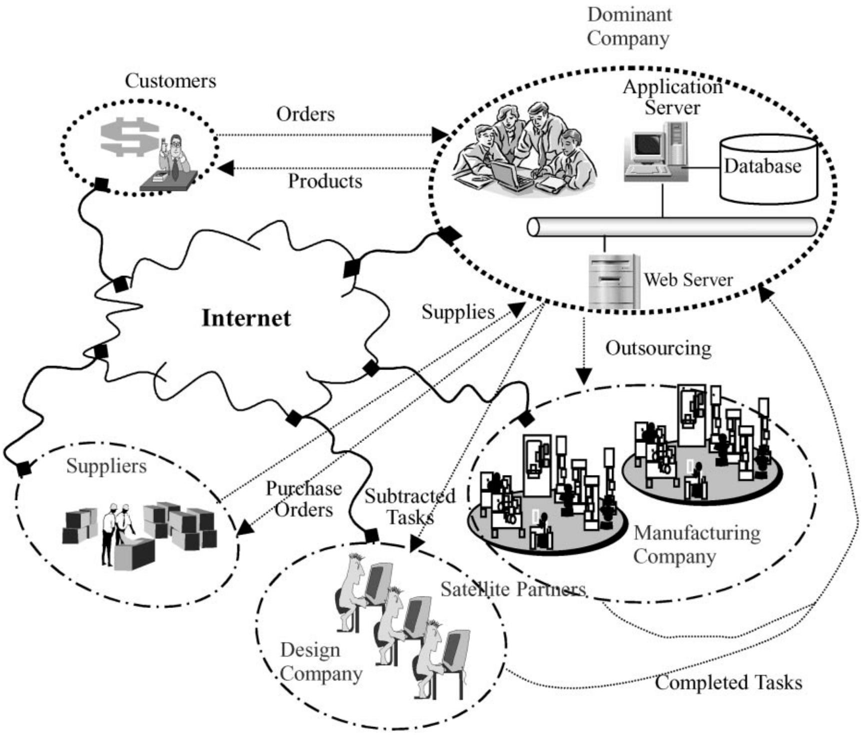

Fig. 1. Different types of participants in remote manufacturing.

engineering drawings, documents and the relational databases.

3. The data sources often run in heterogeneous environments consisting of diverse hardware platforms and operation systems.
4. The multiple data sources are often inherited from many legacy systems.
5. Information integration should be open and flexible in remote manufacturing environments where the multiple data sources vary in accordance with the possible participants.

2.1. Integrated product data model

To improve global performance of the remote manufacturing, we have decided that all product data be managed in the centralized product database running on the main server inside the Robot Company. The robot product data should be managed on the basis of an integrated product data model and through multiple configuration control of consecutive lifecycle phases. Creating comprehensive product models for the robots to be manufactured is identified as the basic prerequisite for developing and maintaining the centralized product database. The product model should have following features. It should comprehend and manage all product-related data such as drawings, versions, engineering changes, routings, constraints and interdependencies. On the other hand, it should also be simple to manage, reducing maintenance costs. It should elaborately define the basic elements such as purchased devices, parts and components in a standard format. It determines the robot structures by describing interrelationships and constraints among the elements. The product model should not be static; it rather dynamically tracks the changing status of robot structures through successive stages of the product lifecycles. In this way, all departments in the company and its external partners, suppliers and customers can share consistent and updated product information, ensuring all relevant organization units to have the same version of part drawings and complete proliferation of engineering change notices.

Customer orders are managed as independent projects based on the "To-Order" manufacturing philosophy. Requirements for industrial robots are typically customer-specific, there are always structural and functional innovations for the newly ordered robots. The diversity of customer requirements result in a lot of robot variants. If all these robot variants are handled separately in the product database, the product designs increase explosively. It is difficult to store all the possible variants separately in a database because of data redundancy caused by commonality between variants. Further it is difficult to have insight into the family of variants as the relationships between variants are not stored in the database and thus lost for the user and everyone else [3]. To reduce data management complexity, we need to categorize the manufactured robots into several basic types. All the robot variants are treated as different configurations of the basic robot types subject to certain customer constraints. The concept of multiple configuration management is leading to development of reconfigurable robot products on basis of standard and specific components, which enhances customer satisfaction and increases market responding speed.

As shown in Fig. 2, the integrated product data model (IPDM) provides a conceptual architecture to manage the entire product-related data, drawings and documents. The IPDM basically consists of parts, modular components, product structures (multiple configurations), drawings, routing files and project files. Within the framework of the IPDM, all parts, components, peripheral devices and end-robots are managed as objects (more frequently called items). Data related with items are normally classified into two categories: structured data and non-structured data. The structured data are item specifications or characteristics, such as weight, size, material and parent item number. The structured data are stored as item attributes in relational databases. The non-structured information includes item inspection procedures, standards and routings, which are difficult to store in the relational data structure. This kind of information is compiled as Microsoft Word and Excel files that are associated with items.

The IPDM offers categorized access interfaces that allow users to obtain controlled views of the product information on basis of identity validation. Interfaces filter the product data to frame limited views for different groups of users. According to application domains, there are four categories of interfaces. *Market Interface* provides the information supporting product advertisement, customer order processing and management, technical services and customer participation. *Design Interface* provides both internal and external designers with engineering information, such as geometrical data, drawings and structural relationships among components. *Supply Interface* frames the view of inventory, purchase and supply related data, to support the material acquisition, warehousing and supply processes. *Production Interface*

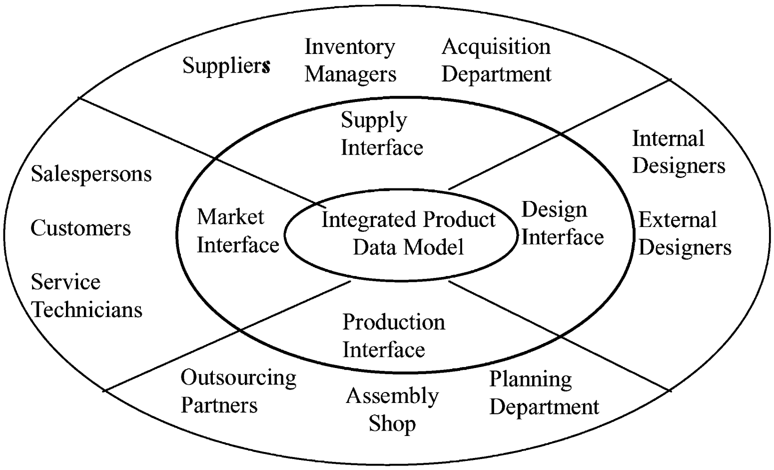

Fig. 2. Integrated product data model.

casts data views on the fabrication and assembly processes.

The categorized interfaces support data encapsulation and modular system developments. They permit people from different sectors to obtain different views and share the common product data. With access to the completed and consistent product database, everyone can successfully conduct their own jobs. For instance, designers can access to the product geometry data and drawings. Production professionals will view the planning and scheduling information, including process routings. In addition to watching product demonstrations and participating in the design and fabrication processes, customers can also get service support through Web browsers, with just a few clicks.

Advantages of the categorized interfaces also include efficient data security control and consistency management. The interfaces permit each user to access a specific portion of product data that is authorized in accordance with his or her role. After checking a user's name and role, the identity validation mechanism determines what product data can be accessed. The interfaces provide check-in and check-out functions to maintain data integrity. The product documents checked out by one user are frozen to avoid being changed by other users in parallel. All released product data are checked into an electronic repository where they are protected from unauthorized modification.

2.2. Robot configuration management

The dynamic manipulation processes of the integrated product data model are realized by the configuration management. As shown in Fig. 3, robot products generally go through the following lifecycle stages, such as requirement specification and conception design, detailed design, fabrication and assembly, installation and operation. Robot manufacturing always begins with customer requirement specification, conception design and quoting. Quite often the cases are as follows. The salespersons go to convince the potential customers that robot implementations would be suitable solutions to their problems. Sometimes, vice versa, the customers first contact the company, consulting possible robot implementations. When a preliminary intention is consolidated, customers will provide their basic requirements of functions, performance targets, and constraints. These requirements are represented in words and sketches. Clearly understanding customer requirements is very fundamental to increase customer satisfaction and to reduce costs of rework and modifications brought into existence by misunderstanding. The ambiguously expressed requirements must be iteratively clarified and precisely specified, eliminating possible inconsistencies. With the confirmed and well-documented customer requirements, designers first develop a set of product conceptions. Designers present the product concept options to customers, seeking comments and suggestions. After a series of modifications, customers decide to choose one product concept. Then, customers are to be quickly provided with product quote-prices and delivery dates, which are calculated from the estimated resource consummations, balances of facility capacities and loads, and business profitability. This invokes the business negotiations between the company and customers. At the end of business negotiation processes, business contracts are signed and robot orders are placed down.

In the detailed design stage, the whole robot structures are refined and decomposed into components and parts. After completing preliminary structural layout designs, the company develops detailed component and part design with some external institutions. The geometric and functional parameters are carefully designed for the in-house built components with CAD tools. Functional parameters and critical mating parameters are determined for the standard components to be purchased outside. The company generally assigns most mechanical design tasks to its design partners and synchronizes the design processes.

In the following fabrication and assembly stage, all parts (components) are subcontracted to the fabrication partners who possess high fabrication capabilities, and only the final assembly processes are retained within the dominant company. The fabrication partners and suppliers, respectively provide the dominant company with the fabricated parts (components) and the standard components according to schedules. The company ensures that all the parts and components to be received in time by closely auditing and coordinating the fabrication processes within its cooperation partners. The delivery schedules are also carefully arranged for the standard parts (components) purchased from the suppliers. Finally,

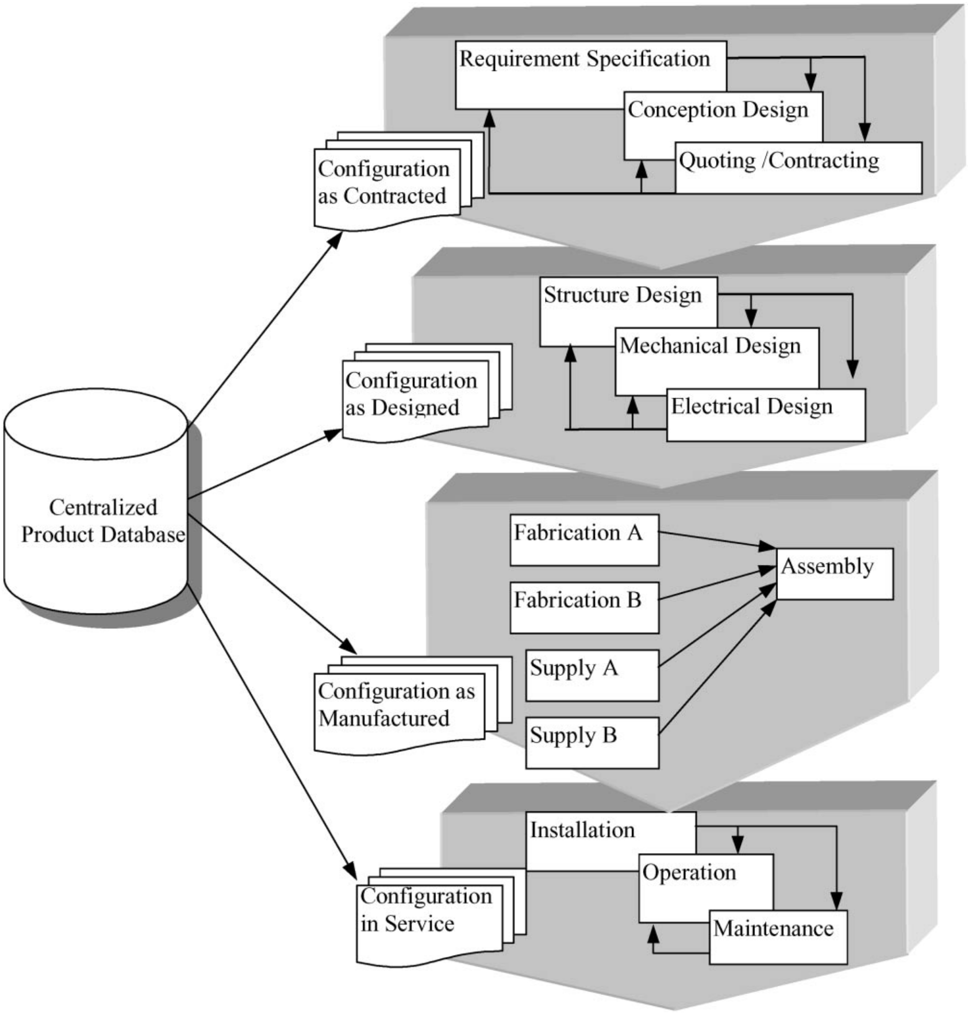

Fig. 3. Robot lifecycle stages.

all the components are assembled into robot products, which are further tested and adjusted. Here, close controls of component lead-times are essential to secure the delivery dates of end products.

After having the robots installed on-site, customers would validate performance status and conclude the orders. The dominant company continues to provide technical support services for robots in operation. In the past, customer support processes were conducted in the following ways. After installations, the operation feedbacks and failure notices are collected from customers via phone and fax. One service engineer would suggest customers a set of diagnostic operation and steps to fix the possible problems. If the problems could not be identified and solved through remote instructions, a service engineer was obliged to regulate and to fix the robots on-site for customers. One of the disadvantages of such customer support process is that it is very time-consuming and expensive. Another critical disadvantage is that there were no well-maintained product service databases, but only some incomplete and inconsistent document records.

As mentioned above, in the past, the coordination and synchronization processes were generally carried out by conventional communication means. Various product data concerning customer orders, design and fabrication, and the numerous documents were not strictly associated with each other and handled in a scattered way. With the IPDM, the dynamics of the product data is presented by the concept of configuration transformations. Product data are managed in association with different configurations, such as contracted, as-designed, and manufactured, and as delivered (in service). Product data evolve from initial information configurations as contracted to final information configurations as in service, in accordance with the lifecycle stages of the physical robot objects.

Efficient management of the multiple information configurations maintains product data integrity throughout product lifecycles, reducing information amounts and manufacturing complexity. The robot configuration management is also a necessity for the company seeking to increase customer satisfaction and to optimize manufacturing performance over the entire product lifecycles. Configuration management maintains relationships among parts, components, changes and data. Product configuration management synchronizes and audits data manipulation processes, and accounts data status by managing changes. Effective configuration management supports the company rapidly developing customized products and reducing work inefficiencies, reworks, mismatches and delays caused by frequent change. The basis of robot product data management is the transformation processes of the multiple robot configurations. Multiple robot configuration transformations have two means. First, multiple configurations indicate that a number of physical robot variants are transformed from a basic robot type. Therefore, these physical configurations (configured robot) share much in common with regard to structure and at the same time bear some difference. Second, from the point view of information modeling, types and contents of product data to be emphasized vary with the lifecycle stages of a robot. Throughout its lifecycle, product data of a robot are maintained as different information configurations at design, production and utilization stages.

In some sense, a robot lifecycle from conception to disposal may be viewed as reconfiguration processes. In the configuration management processes, bill-of-materials (BOM) and configuration are two interwinding concepts. A generic BOM is used to describe the general structure of a group of robots. The generic BOM of a robot family may result in many configurations to describe the specific structure of every robot. In fact, BOMs and configurations are abstracted information models to represent the products. Consequently, BOMs and configurations should be dynamically changed to reflect product development processes, thus resulting in different BOMs and configurations for the same product at different lifecycle stages (as shown in Fig. 4).

First, in accordance with customer requirements, the conceptual robot designs are developed, reflecting the as-contracted product structures (CBOM). Then, the constituent items are defined, with which the documents are associated. The as-designed robot structures, the engineering bill-of-materials (EBOMs), are further developed by adding items and engineering change notices (ECN) to the CBOM. For each basic type of robots, the design structure (EBOM) is represented by the hierarchical relationships between part items and component items. The hierarchical design structure is described in the IPDM as a tree where nodes designate the items and branches indicate the composition relationships between items. The number of nodes and depth of branches also reveal the complexity of product structure. As mentioned above, the robot market is strictly customer-driven and no robot ordered exactly matches those already produced in the past. Consequently, variant designs are always performed over the existing robot designs and different customer requirements result in series variants of a same robot type. These variant designs are managed as different robot engineering configurations obtained by applying constraints of customer specifications.

To facilitate production, the as-designed robot structures (EBOMs) should be changed into the as-manufactured structures (MBOMs) to reflect the constraints of process routing and assembly. The MBOM first determines which items are to be fabricated and which items are to be purchased. Second, MBOM indicates precedent constrains in the fabrication and assembly processes, revealing the robot structure being made. In addition, the MBOM consists of the process routings, material allotments and assembly operation instructions. Procedural rules are developed to help to transform the robot EBOM into the MBOM. Relating with each specific customer order, specific manufacturing configurations of robots are derived from the robot MBOM. And these manufacturing configurations of robots are used for planning and

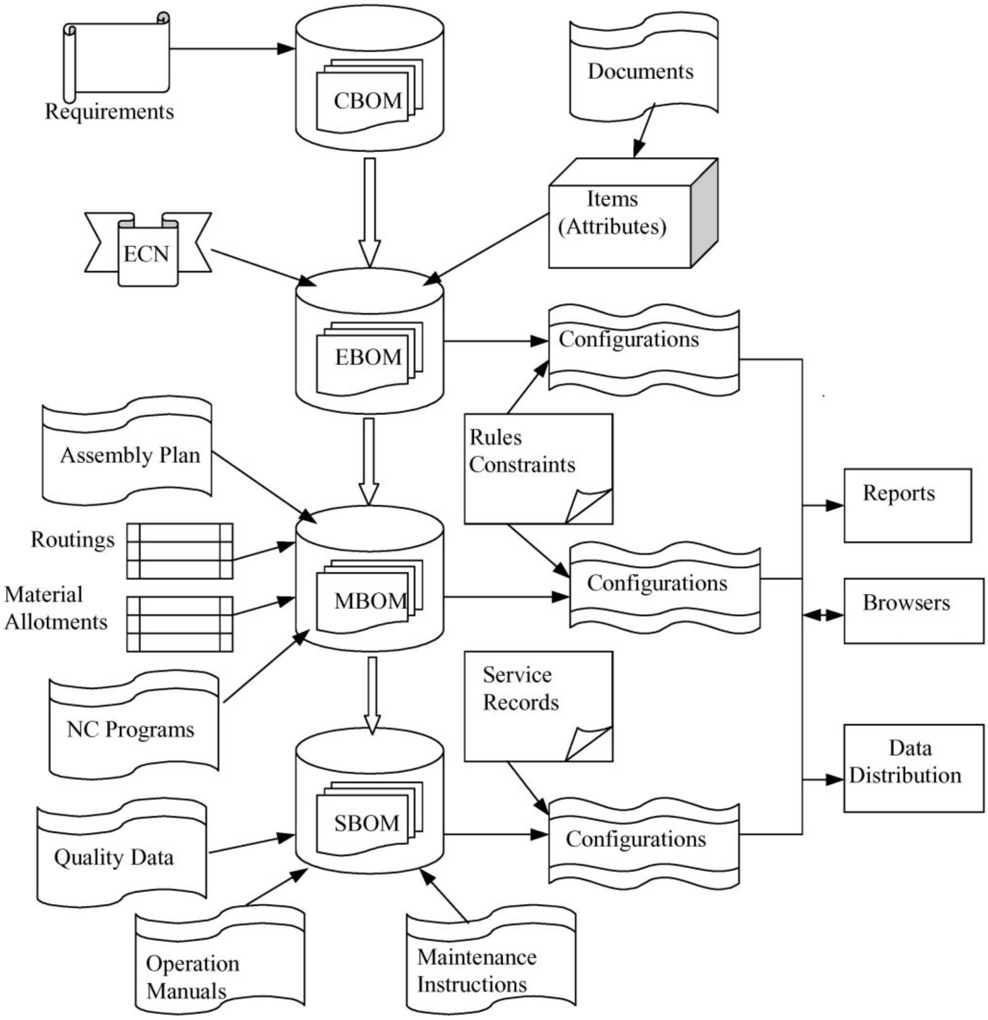

Fig. 4. Robot configuration management.

scheduling, purchasing, fabrication and assembly operations. After assembly processes, the as-manufactured structure MBOM of a robot type are transformed into the service structure (SBOM) by adding information about quality, maintenance instructions, auxiliary items and service records. Specifically, when a configured robot is assembled, its manufacturing configuration is transformed into service configuration by adding customer-specific data and information of the production unit, operator and quality. The service configuration is used to keep track of robot installation, utilization, maintenance and disposition. The service configurations are actively maintained as long as the robots are in operation.

3. Application system architecture

In the remote manufacturing environment concerned, the Robot Company plays a dominant role. From the point view of the company, there are two basic types of information flows. In forward information processes, product data from the centralized database are distributed to customers, suppliers and partners. In the backward information process, the commercial transaction data and production data are collected from customers, suppliers and cooperation partners and entered into the integrated database after further processing.

During the remote manufacturing processes, an integrated information application system is required to validate and control access to the product database, to generate and record various data and files. The application system is also required to facilitate a variety of planning, managing and controlling functions, and to generate specific reports in the product life cycle. Many commercial systems such as engineering data management (EDM), product information management (PIM), technical data management (TDM) and product data management (PDM) are available to efficiently manage product data and to control change. And many business systems like enterprise resources planning (ERP), such as SAP's R/3 system, can carry out sophisticated manufacturing planning activities on basis of effectively managing product data. However, these commercial systems are found not suitable for the specific remote manufacturing cases. These systems are too large and complicated, offering many redundant functions and requiring long implementation times. On the other hand, these systems are deficient of functions uniquely required in the remote robot manufacturing, such as remote data access and collecting through Web browsers. In fact, the required application system should unify some functions of PMD systems and ERP systems, while supporting information transactions over the Internet. Therefore, a specifically tailored remote manufacturing system is developed to manage and control these information flows.

3.1. Information management system architecture

The remote manufacturing system has a hybrid architecture of client/server and browser/server. The client/server architecture is adopted for internal functions and data processing, while the browser/server architecture is used for external information handling processes. As the organization structure and business processes within the company are much more fixed, client programs with sophisticated functions are developed for inside users. While the outside application circumstances frequently vary and are more unpredictable, it is impossible develop and maintain client systems for the changing external users. External users' access to the product database can only be realized via the common platform-neutral Web browsers. Web-based applications exert no special requirements on information infrastructures of partners, supporting dynamic cooperation. The browser/server architecture allows developing professionals to focus on development and maintenance tasks on the server side in spite of the increasing number of distributed customers.

As shown in Fig. 5, the system is composed of five sub-systems. *System Management* is responsible for manipulating and maintaining the centralized product databases. It keeps metadata (or data about data), such as interrelationships among data objects and user authorizations. These metadata are used for conducting database management operations to maintain product data integrity and consistency. Users are categorized into many groups, to which different access authorizations are granted. For each access to the product database, the user identity is first validated and access authorization is determined, ensuring the user has appropriate view of the global product data.

Market/Customer Management has a wide range of functions. It is responsible for the company presentation and product advertisement over the Internet. With browsers such as Netscape Navigator or Internet Explorer, remote customers may explore the product catalog and watch the multimedia demonstrations to get a comprehensive understanding of the product lines. Functions of remote order entry and processing over Internet are also supported. Elaborately developed Web interface forms permit customers to specify their requirements, inquiries and their detailed contact information. By clicking the submission button, customers can upload the order information to the centralized product database. The uploaded order information will be automatically processed and prompted to sales department for preparation of conceptual design and business contracting. During the robot conceptual design process, designers will go to visit customers, consolidating the requirement specifications. By connecting to the centralized product database via the Internet, designers can access to the existing product designs and rapidly develop conceptual variant designs. Simultaneously, designers

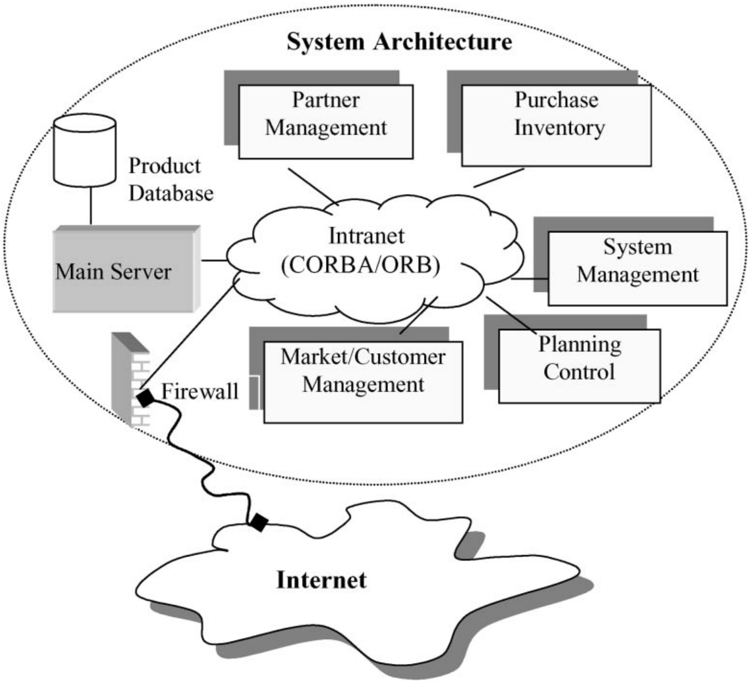

Fig. 5. Application system architecture.

present the conceptual product designs to customers and allow for full customer participation. The on-site conceptual product design conducted jointly by designers and customers considerably shortens the lead-times and increases customer trust and satisfaction. With input of the product conceptual designs, the quoting function will help sales managers to quickly develop business quote-prices with access to the related information, such as production loads, facility capacity, inventory levels and historical marketing data. The product quote-prices are downloaded to customers via Internet browser and the business negotiation processes are also supported by the Web-based system. One important advantage for using the Web-based system in business negotiation processes is that all information is automatically processed and saved for reference in the following steps.

The customer participation in the design and manufacturing processes is supported to develop customized robot products and to offer information services. After signing the contracts, customers are always very concerned with progress status of their orders. In the past, customers would send a lot of inquiries to the company, which spent much time on dealing with these inquiries via phone calls and faxes. Now, the system maintains a specific WebPage for each customer order, dynamically displaying customer order execution status and other interesting information. Customers can also submit their opinions and comments through these WebPages. Another important function is the remote customer support and failure diagnostic. Product manuals and technical guides are coded in hypertext file, allowing customers to download them through Web browsers. A set of frequently asked questions (FAQs) is elaborately programmed into appropriate WebPages. Further more, an on-line training and diagnostic process is developed to help customers to solve common technical breakdowns. These Web-based customer support services is a very important strategy to win customers who usually consider customer service a decisive factor in selecting the complicated products.

Purchase and Inventory Management is basically an internal function that first conducts material requirement planning for each new customer order, on basis of robot engineering structures. It counts and controls the inventory level of the assembly components. It accordingly develops purchase plans of the standard components, devices and auxiliary items. *Partner Management* is completely an internal function that operates an electronic data vault about various partners, including the design partners, fabrication partners, distributors and suppliers. This function also keeps track of the performance of these partners. The creditability and performance records of partners in collaborative manufacturing are periodically evaluated. The evaluation results are used as basis for partner selection and coordination. The client/server architecture is adopted for the two application systems above mentioned.

Planning and Control carries out the functions of planning, scheduling, monitoring and coordination. More specifically, it is first responsible for developing detailed robot delivery schedules for the accepted robot orders, which distinctly determines the due dates and product status at the major design, fabrication and assembly phases. The robot delivery schedules are determined as functions of contracted end-product due dates, potential human and facility capacities, current work loads, the relevant historical data, etc. These robot delivery schedules are used as important references for following planning and coordination processes. The system helps to develop related acquisition plans and to keep track of the supply processes. With reference to the delivery schedules, the company selects design and fabrication partners, to which tasks are subcontracted and outsourced. Specifications of the subcontracted and outsourced tasks are managed in the product databases, associating with the MBOMs of robots. The monitoring function constantly collects actual design and fabrication progress data from the partners through filling out specific WebPages. The collected data are processed; the actual production status is compared with the planed production status. If major differences are found in the comparison, the system will give out alarm information and suggest possible coordination activities.

The application systems have been developed in the Microsoft Visual Java and Visual C++ languages, to support object-oriented concepts and reconfigurability. For the moment, the centralized product database is implemented with the relational database management system ORACLE 8.0 installed on the main computer-server of the dominant company. Remote external users download from and/or upload to the product database various data. The data sources at the remote users are separated by the neutral front-ends (the browsers). The remote users are able to operate on the centralized product database, while it is relatively difficult for the applications in the dominant company to directly operate on data sources at the remote partner ends. A CORBA-based integration framework is proposed to achieve the dynamic interoperability among the data sources distributed.

3.2. Information integration framework based on CORBA

The CORBA-based architecture provides the ideal means to support distributed transactions involving multiple application objects and spanning multiple data sources over the Internet and company Intranets. CORBA also supports transactions across heterogeneous platforms such as NT and various Unix platforms. The information integration framework is based on Web, Java/RMI and CORBA standards (as shown in Fig. 6). The CORBA standards compliant product Orbix 2.0 by IONA is used in developing the framework.

Within the integration framework, data sources are encapsulated into information objects, and are defined and registered by the brokers. Information objects of data sources can be easily added and/or cancelled when the related enterprises take part in and/or withdraw from the remote manufacturing environments, allowing flexibility and scalability. The application systems are encapsulated as application objects, which are connected through adapters to CORBA compliant object request broker (ORB) bus across the Internet and company Intranet. Remote users create http connections with the Web server containing data sources, download the necessary Java applet and HTML documents over the Internet by using browsers. Then the remote users run the Java applets on their virtual Java machines, to create connection with CORBA request/service brokers embedded in the Web server. By invoking the request/service brokers, remote users can have access to various design and manufacturing data sources linking to the CORBA bus, thus they can inquire, modify, commit and transmit related product data.

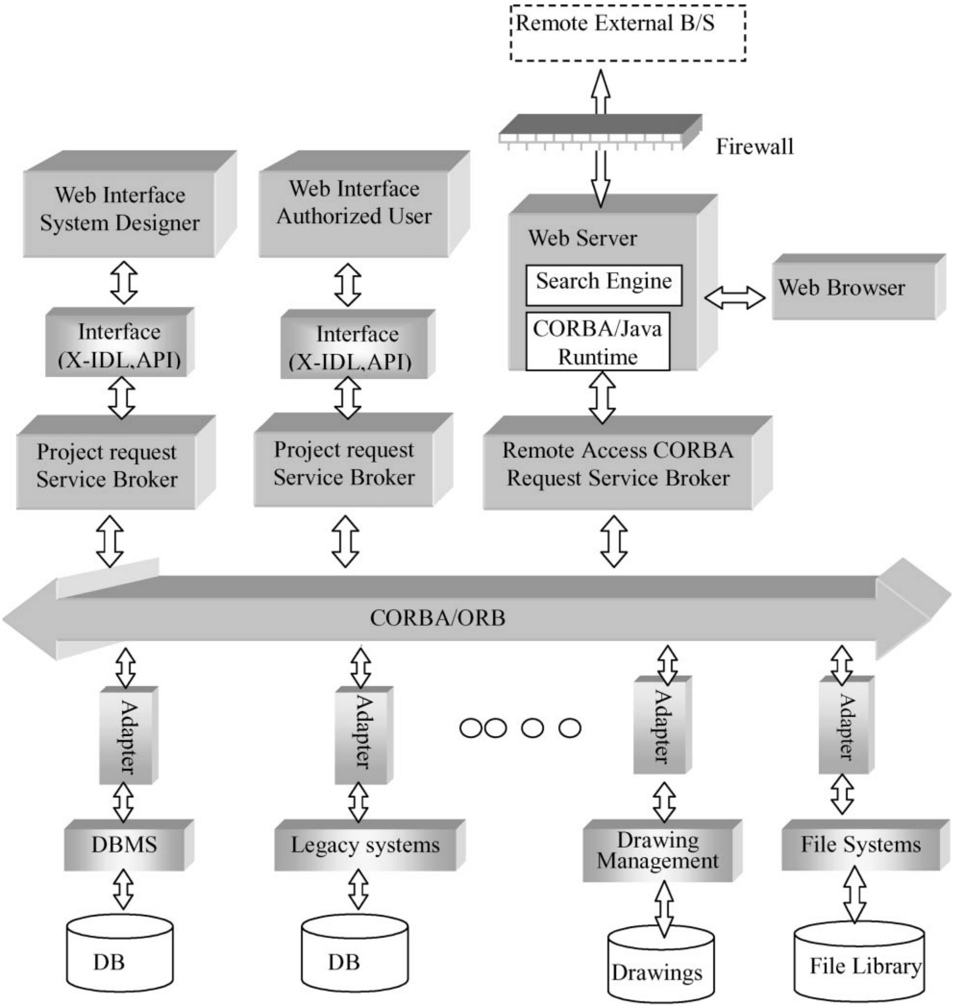

Fig. 6. Information integration framework.

The underlining essence of the framework is that all the information transactions are conducted with help of the brokers. The CORBA ORB provides the information infrastructure to link the remote data and application objects. The brokers maintain the information transparency in the environments, separating application objects from the details of data access. When an application object issues a request, the brokers will find the right target data object, invoke it, deliver it the message, and return the response messages to the application object. In this way, application systems realize access to and operations on remote data sources.

4. Conclusions

The accelerating change is shaping all aspects of today's manufacturing industries. Over the last decades, manufacturing shifted from traditional mass-production towards customer-responsive production. Remote manufacturing increases market competitive advantages by establishing task-oriented ‘‘virtual companies’’, supported by enabling information technologies. The momentum for these collaborative partnerships is the growing acceptance that no single company can carry out all the activities required to bring products and service to the market. Remote manufacturing is a strategy permitting a company to concentrate on its core-competencies and to leverage external talent sources in fields of its non-competent areas. Remote manufacturing reduces manufacturing costs in terms of labor and resources, and increase the market shares because customers feel affinity of the customized products.

Remote manufacturing implementations inevitably depend on the development of a comprehensive product data model and the enabling information infrastructures over the Internet. A well-developed product data model should have following characteristics:

1. Object-oriented: encapsulating product data into data objects to reduce management complexity.
2. Comprehensive: capturing all product data required and generated throughout the whole product lifecycles.
3. Integrated: organizing various product data in a logical way to allow multiple users operate on the same data model, while maintaining data integrity.
4. Dynamic: reflecting product configuration transformation process through different manufacturing stages.

In the remote manufacturing environments, many planning, design and fabrication applications need to operate on multiple heterogeneous data sources. The information infrastructures are very critical to achieve the interoperation among the dispersed multiple data sources. CORBA is an open distributed infrastructure that facilitate many network programming tasks such as object registration, location and activation. And CORBA standards compliant systems are widely accepted to integrated multiple heterogeneous data objects and application object across company borders.

With implementations of remote manufacturing techniques, the company realizes the following competitive advantages. Production management is smoothly streamlined, enabling more prompt response to market requirements. Web-based techniques allow easy access and distribution of product data among customers and partners over the Internet. WebPages coded in hypertext and Java Applets are used for coordinating activities among the cooperation partners, and for providing customer support services. Dynamically maintained WebPages allow customers to participate to some degree in the manufacturing processes. It is observed that production costs, leadtimes and inventory levels are obviously decreased. Enhanced communication also help to improve customer satisfaction and win more orders.

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