Design and Development of a Platform for Internet-based Collaborative Product Development

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ABSTRACT

In order to accomplish collaborative product development in the area of engineering, a work platform is needed to support all-sided collaborative work by the different development partners at geographically different locations. The platform is established on the basis of a three-tier architecture which provides four advantages over Client/Sever model. First of all, it can improve the capability and scalability of the development system. Secondly it can enhance the functional reliability. Thirdly it can transfer main management works to application servers to reduce the overall expenses. Finally it can increase the feasibility and development efficiency. In a typical Collaborative Product Development (CPD) scenario, design work is always over emphasized, while expert supervision is paid little attention. So, it is necessary to build the CPD platform for design and evaluation by Computer-Supported Cooperative Work (CSCW) technology and the Internet technology. This paper introduces the system functions, benefits and further challenges. Then key technologies, such as concurrency control mechanism, shared whiteboard collaborative control strategy, are analyzed in detail. It is proved that the system helps to enhance the product development efficiency.

Keywords: Computer-Supported Cooperative work, Concurrency Control, Shared Whiteboard, Computer Numerical Control.

1. INTRODUCTION

The competitive advantage in manufacturing has shifted from the mass, make-to-stock production to the customer-driven one that is based on fast responsiveness and flexibility [1]. In the research area of product development, these changes lead to an urgent need for an effectively collaborative work among development partners such as employees, customers, and suppliers. Research work has been conducted on some of these issues such as concurrent design environments (Colton & Dascanio 1991), (Cutkosky & Tenenbaum 1991), (Gay et al 1993), and computer-supported cooperative work (CSCW), (Benford et al 1993), (Gronback et al 1993), (Xu et al 1996) [2]. In a CSCW environment, collaborative product development (CPD) is an area for intensive research. American Agile Manufacture Enterprise Forum had organized a research named "Best agile practice reference base" (1994) and the first reference technology was integrated product and process development [3]. The aim of EurocoOp project in Europe was to develop a distributed collaborative work system [4]. In Asia, there has been an annual international reference: "CSCW in Design" since 1996.

Computer-Supported Cooperative Work (CSCW) is primarily concerned with people. It is an environment where computers provide support to a group of people to accomplish a common goal or task. More concisely, CSCW is a set of software, hardware, language components and procedure that support a group of people in a decision related meeting [5]. CSCW is the mechanism to support the work activity of a group of people working on a product, research area, topic or scholarly endeavors with the help of computers. For instance, brainstorming to generate ideas, structuring these ideas and then evaluating them can be facilitated by CSCW system [6].

With the great progress of Internet and World Wide Web technologies, the approach to collaborative product development has been evolving rapidly. Web technology is playing an increasingly important role in developing collaborative product development systems [7]. The web has been a successful platform for collaborative work for several reasons: Core initial user groups; Integration of existing information; Use of existing de facto standards; New standards (public and simple); Software platform (public domain, cross-platform and extensible); Cross-organizational [8]. Recently, several major initiatives and projects on collaborative product development in America and Europe have adopted the Internet technology as their collaborative engineering infrastructure [9].

A CPD platform should encompass the following characteristics to ensure success:

- ***Distribution***: In the current development environments, development teams are usually distributed and located at different geographical sites.
- ***Interaction***: Development teams must interact with each other.
- ***Dynamic***: The process of development, the task allocation and the state of equipment are all dynamic.
- ***Collaboration and conflict***: Collaboration and conflict among team members are unavoidable.
- ***Multiplicity***: The activities in the process of product development are multiplicity.

So, the CPD platform must be a distributed system, and should integrate functions such as process management, data management and communication.

In a typical CPD scenario, product design and development is always emphasized aiming to improve enterprise production efficiency. However, expert

supervision and evaluation of the product design and development is paid little attention. In fact the expert evaluation is very important, which accompanies the design and development throughout a product life cycle. They are both inextricably linked to the technology of product development. How to integrate the design and the evaluation? The primary goal of building the CPD platform is to bridge the gap between product design and expert evaluation and facilitate remote application development and execution.

This paper is organized as follows: after an overall survey of related work in the field of CPD, we present a system architecture based on three-tier model in Section 2. Then we describe collaborative product development processes on the platform and discuss all major components in detail in Section 3. In Section 4 we present function characters and in Section 5 we pay a great attention to key technologies of the system implementation. An example is given to highlight the most important features of the platform in Section 6. The last chapter covers benefits and deficiencies of the CPD platform.

2. SYSTEM ARCHITECTURE

To serve the changing needs of designers and experts, we propose to develop CPD platform architecture to support the product development. Like other product development systems, the CPD platform follows three-tier architecture as presented in Figure 1.

One-tier architecture was widely used prior to 1980s. The typical feature of the one-tier architecture is its self-contained monolithic program that consists of a GUI, processing logic and data store as a whole. Two-tier approach took over in the mid of 1990s. This architecture divides an application into two separate tiers, namely, client and server tier (Client/Sever). Users interface and logic processing both reside in the client tier, whereas its associate data vault resides on the server side. The major benefit of a two-tier system over a one-tiered system is that it makes the client side 'thinner' [10]. Two-tiered architecture allows faster processing than a single-tiered system. However, the client can still become 'too fat' as the application gets more complex. This will result in slow response and processing from the server.

In early 1996, the emergence of the three or multi-tier architecture makes the client side much thinner by separating the 'fat' client into two parts - user interface and logic processing. The result is a three-tier structure which allows faster response and processing of users' requests and facilitates reuse of application. As shown in the figure 1, user browsers form the client tier, the database servers form the third tier, the web server and the application servers (including a product design application server and an expert decision application server) as the middle tier. In this way, the designers or the experts can use their browsers to visit the web server by HTTP protocol. The web server redirects the client requests to the appropriate application server. Alternatively, the designers or the experts visit directly the application by TCP/IP protocol. Then the application servers access to data in back-end servers, process it and return the result to the user. This model provides four advantages over Client/Sever model. First of all, it can improve the capability and scalability of the development system by adding the number of application servers or by balancing the load between application servers. Secondly it can enhance the functional reliability by allowing application servers to run on different machines to avoid the single-point failure. Thirdly it can transfer main management works to application servers to reduce the overall expenses. Finally it can increase the feasibility and development efficiency.

The CPD platform, as shown in the figure 1, has five databases to support:

- ***Product Design Database****:* used to store product design data and models, such as geometric data and non-geometric data, which are required for the convenience of designers and experts in the process of product design .

- ***Designer Information Database****:* used to store

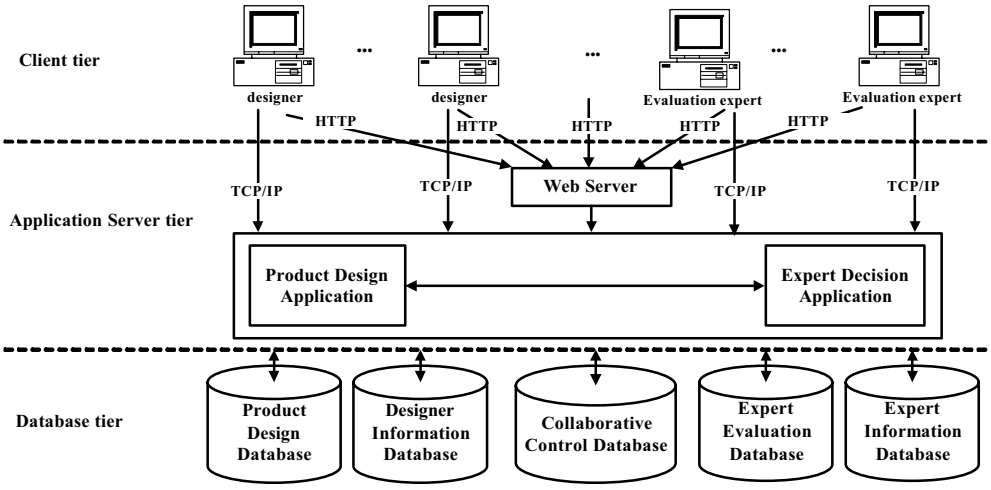

Fig.1. Three-tier Architecture in CPD System

information of designers, such as personal data, research condition, achieved accomplishment etc. to enable experts to select right designers of a project.

• ***Collaborative Control Knowledgebase****:* used to store criteria, constraints or other formalized knowledge that apply to specific collaborative managements to guarantee the integrity and consistency of the data with regard to all its users and negotiate or adjudicate conflicts when they occur.

• ***Expert Evaluation Database****:* Expert evaluation documents, including expert evaluation form, conclusive opinion etc.

• ***Expert Information Database****:* used to store information of experts, such as personal data, expert authorization etc. convenient for selecting suitable persons to participate in the evaluation.

3. DEVELOPMENT PROCESS

In a product development project, the work is often divided into phases related to some kind of decision-making. The phases often contain a set of concurrent activities delivering the 'material' needed for decision-making.

The overall product development process is here divided into four phases. (See Figure 2)

• ***Project Approval****:* The project hoping to be developed on the CPD platform must meet certain criteria. Firstly, the project owners must be CPD members to qualify for entering the CPD platform before presenting application forms. Secondly, the experts with qualification for evaluation are organized to participate in the process of collaborative evaluation on the Internet, including 'real-time' discussions by videoconferencing if necessary. Finally, confirm the project according to the evaluation result.

• ***Cooperation Application:*** The platform allows all members of CPD to compete for qualification for doing some development works. The experts will begin to evaluate after closing date of cooperation application, according to submitted application forms. The platform provides automatic mechanism to sum the evaluation result up. Besides, the experts can make decisions by online discussions of videoconferencing.

• ***Project Development:*** The CPD platform offers tremendous opportunities for the sharing of information among product development team members who may well be distributed in terms of both time and space. Besides, the platform provides the designers and evaluation experts with a group-based desktop (shared whiteboard and chat for example) as a place to meet and work synchronously. This is a key phase, mainly finished by designers and related members on schedule collaboratively.

• ***Project Conclusion:*** After the project is finished, the designers must make a conclusion of the whole development work, then submit it to experts. The experts will make conclusive comments, and the CPD platform will sum all expert score forms up automatically. However only the expert having the concluding authority can conclude all the evaluation forms, and organize the experts for evaluation in the form of videoconferencing. At last the experts will arrive at a decision and send it to the project approval units, developing units etc.

As you can see, the experts will play an important part in the process of product development.

4. FUNCTION CHARACTERS

In terms of capabilities, six basic functions are supported by CPD platform:

• ***Collaborative work management***, which organizes the work between designer and designer, or designer and expert, or expert and expert, and facilitates communication

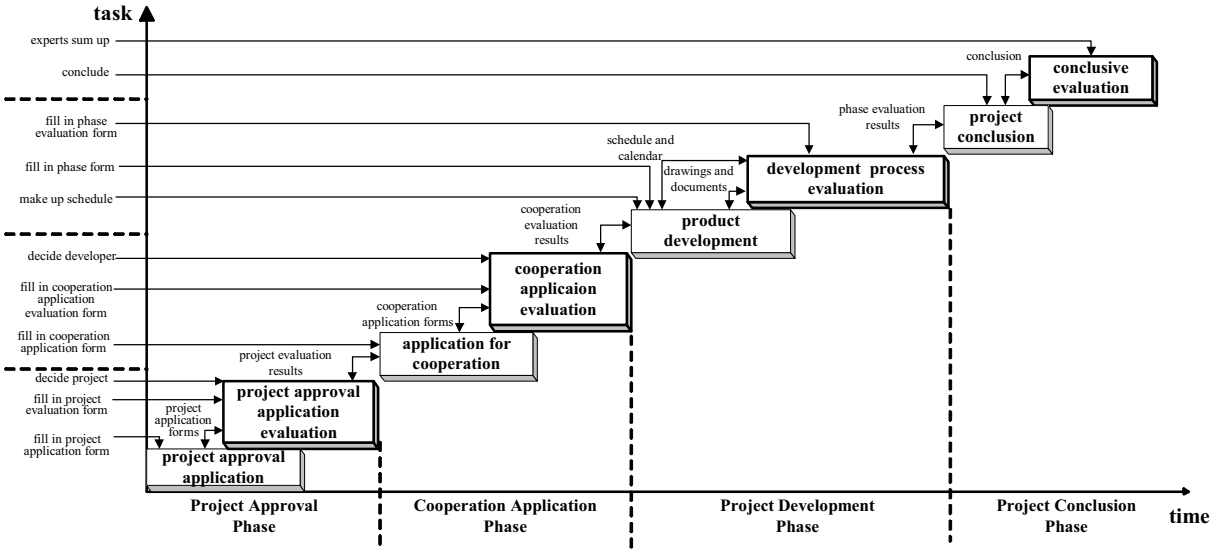

Fig.2. Product Development Process Model

with each other, and allows coordination between processes, resource scheduling, and project tracking.

- ***Workflow and process management***, which controls procedures for handling various drawing data and documents, and provides a mechanism to drive a product development with information.

- ***Design data process***, which provides design data edit and process templates to aid designers to edit and manage the related design data and documents.

- ***Evaluation document process***, which provides event registration template and evaluation report edit template to aid experts to supervise project development and security, and to edit, manage, and release evaluation documents.

- ***Videoconferencing management***, which provides audio and video tools and shared whiteboard tool to help designers and experts to communicate synchronously.

- ***Asynchronous communication management***, which provides multimedia e-mail tool or File Transfer tool to pass meeting message, event notification, evaluation result etc. to users.

5. KEY TECHNOLOGY

System Development Method

The web-technology is an enabling tool for overcoming the obstacles of communication between the different partners, as well as making the transaction better implemented. Previous efforts to provide a web-browser-accessible system have employed static HTML pages linked together in a hierarchical manner [11]. However, HTML pages alone could not provide the "interactivity" required by this application. To provide dynamic content, Active Server Pages were used. They differ from regular HTML pages in that they contain a script which interfaces with the database to insert, delete, modify and/or query data as desired, and to generate the corresponding HTML pages dynamically. For instance, many Active Server pages, such as user login web page, form submission web page, etc., were developed to enable designers or experts using Windows-based PCs or workstations to interact with the databases easily.

To ensure a high degree of portability, we implemented the applications in C++ language, such as shared whiteboard tool, group decision system etc. We adopt the class hierarchy for the shared object to handle events in white board tool.

```
Class  ProcAbs-Class
{ virtual EventProc-1 (...);
...
virtual EventProc-N (...);
};
Class  UserProc-class: public ProcAbs-Class
{ EventProc-1 (...);
...
EventProc-N (...);
};
Class  NetProc-class: public ProcAbs-Class
{ ProcAbs-Class *pUserEvent;
NetProc-class (ProcAbs-Class *pUserEvent)
{this->pUserEvent= pUserEvent;
};
EventProc-1 (...);
...
EventProc-N (...);
...
};
```

UserProc-Class and *NetProc-class* descend from the class *ProcAbs-Class* which contains a collection of methods and data. *UserProc-Class* provides the methods for the communication interface between the shared object and application layer, while *NetProc-class* for the interface between the shared object and network layer. *EventProc-x* method of both has the same parameters to handle the different communication, such as message coding and transmission, which makes it easier to design a communication interface for a new event.

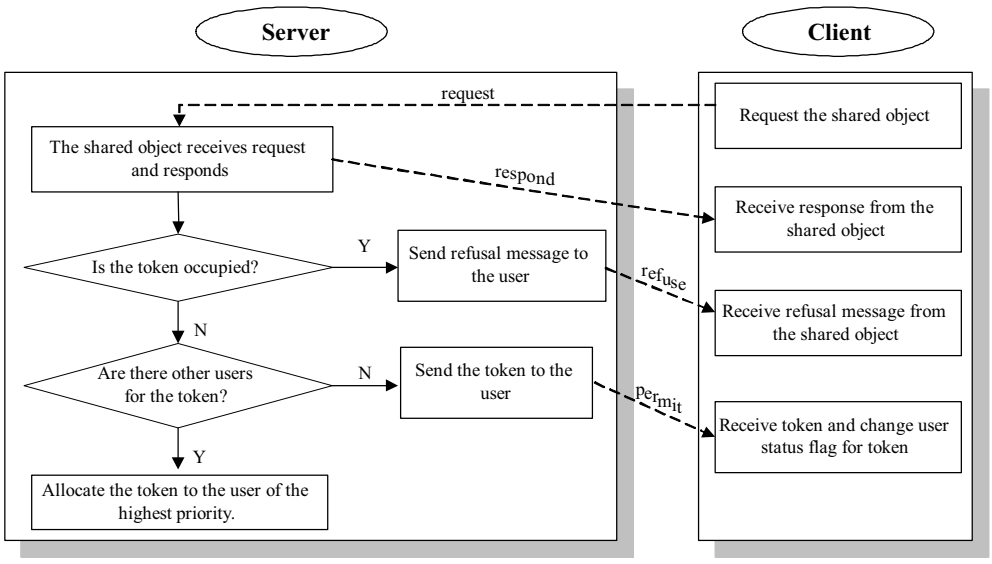

Fig.3. A user requests the shared object

Shared Whiteboard Collaborative Control Strategy

Computer-based video conferencing is one of today's most exciting multimedia applications [12], which provides audio, video, application sharing, and shared whiteboard. The shared whiteboard is often the core component of the video conferencing. It is an online discussion board where developers can contact other users online via the network. The authorized designers and experts can choose the engineering drawing and annotate the drawing with the line, rectangle, circle, and text tools provided by it. Each user sees the result synchronously.

When multi-users want to access the same shared object simultaneously, the conflict is inevitable. How to provide a kind of flexible access control strategy to maintain data consistency? The developed whiteboard turns to token control algorithm to resolve this problem. Each shared object in server is assigned a unique token. The shared object allows only one user to possess its token at a time, i.e., only the user possessing the token can access the shared object. The approach is shown in Figure 3 in detail (taking a user who requests a shared object as an example):

- When a user want to access a shared object, he sends a REQUEST to the shared object stored on the server. The shared object responds to the REQUEST when received.

- If the shared object has been occupied, it will refuse the REQUEST. Otherwise, it will continue to ask if there are other users applying for obtaining the token of the shared object, namely, to ask if the request queue is empty. If the answer is "Yes", it will allocate its token to the user of the highest priority in request queue. Otherwise, it will assign its token to the user.

- The user possessing the token will change his status identifier for the token and send a notification to other users. This allows other users to see which user will possess the shared object.

Concurrency Control Mechanism

Traditional concurrency control mechanisms in conventional database management systems are generally based on one of three main approaches: Two-phase locking, timestamp ordering and optimistic concurrency control [13]. The three concurrency control mechanisms assume that only one version of a data set exists and thus only one transaction can access a data set at a time. This restriction can be relaxed by allowing multiple transactions to read and write different versions of the same data set they access. There does exist multiversion concurrency control mechanisms for each of the above mentioned types of concurrency control. The benefit of this technique is avoiding rejection of operations arriving too late. For instance, if one expert wants to read some design data which is being operated by designers, he doesn't need to wait for the release of the lock for a long time and he can read the old version of the data. With multiversion, such old values are never overwritten and are therefore always available to later reads. The read operation simply avoids rejection by allowing reading an old version. The existence of multiple versions is not transparent to the transactions, and therefore this mechanism is not appropriate for maintaining several versions of a design. Generally we keep two latest versions, one for designers, one for evaluation experts.

6. PLATFORM APPLICATION

After the platform is built, various kinds of applications have been running on it, from Remote Numerical Control to Remote Product Design and Database Management. Take Remote Numerical Control Machining for example.

A user who hopes to cooperate with other partners in starting numerical control machining, can firstly seek suitable partners through the CPD platform. Then he can use his browser on the Internet to open the Numerical Control Machining Panel (See Figure 4), and connect with Computer Numerical Control (CNC) Server by entering its IP address. After finishing connection, the user will transmit existing numerical control machining programs to CNC Server to start the machining, or do numerical control programming by himself and then transmit the programs to CNC Server to start the machining.

Other partners or experts can also make a real-time monitoring and analyzing during the whole computer numerical control machining by using the collaboration tools, such as videoconference system provided by the platform.

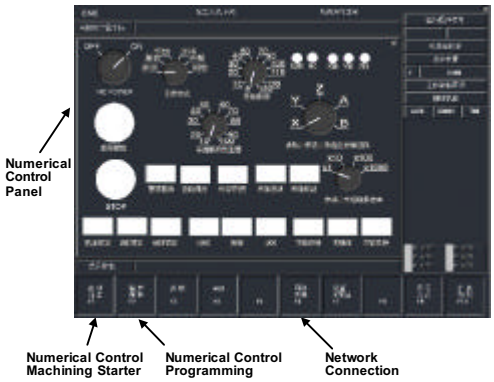

Fig.4 Web-based Remote Numerical Control Monitor

7. DISCUSSION AND CONCLUSION

The CPD platform aims to provide a comprehensive set of inter-working tools for efficient multi-group collaboration using the web technology. The emphasis is on satisfying the requirements of distributed engineering project teams.

Benefits of CPD platform

CPD can achieve multiple advantages in terms of productivity and competitiveness. The benefits can be summarized as follows.

- ***Enhanced product development reliability:*** the platform allows experts to monitor progress, especially in large and/or long-term project and to give early warning of potential delays. Therefore it can ensure the work to be carried out on schedule.

- ***Reduced product development cycle time and cost:*** the platform enables people from all departments and divisions to participate in design, development and process stages of the product throughout its life cycle, which greatly reduces the product development time and cost. Besides, it provides the users with a common collaborative workspace to overcome the communicative barriers.

- ***Provided user-friendly interface:*** Utilizing web browsers as the CPD interface is incredibly cost-effective, simple to comprehend, and capable of supporting almost all users. Furthermore, the web browsers can run on all types of computers and eliminate the need to install and maintain specialized client software on each machine.

Further challenges

As above mentioned there are many advantages of implementing a web-based CPD platform. However, there are also some drawbacks or challenges that should be addressed.

- ***Speed limitation:*** Currently the best medium to accomplish collaboration is Internet [14]. The speed of the communication between clients is directly constrained by the web-technology currently available, which cannot compare to the speed of a local area network (LAN). If enormous quantity and diversity of data exchanges between the users occurs, for instance, a mass of drawings and non-geometric documents need to be transmitted rapidly inside each of design groups, and a mass of decision data are retrieved by experts for desktop analysis, LAN is better than Internet.

- ***Security issues:*** The exponential growth of the Internet in recent years has fostered the importance of secure communication. Security has become a major research work in Internet-based development. The potential to make mistakes during transferring data or information is not totally eliminated by a Internet-based CPD platform. Since this platform requires lots of information transaction through the Internet, security should be a huge issue to be considered.

- ***System functions:*** The shared whiteboard presented in this paper is far from optimal for multi-users' collaborative work. It also almost completely neglects security issues. The system should include a virtual election and voting space, three-dimensional animation for project exhibition, evaluation payment system etc.

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