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Applications of the Web-based collaborative visualization in distributed product development

Chih-Hsing Chu [a,*], Ching-Yi Cheng [b], Che-Wen Wu [b]

[a] *Product Realization Lab, Department of Industrial Engineering and Engineering Management, National Tsing Hua University, Hsinchu 300, Taiwan*

[b] *Department of Computers and Information Sciences, National Chao Tung University, Hsinchu 300, Taiwan*

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Abstract

This paper illustrates applications of the Web-based collaborative visualization (WCV) in distributed product development. Three software prototypes were developed using the WCV technologies. The first one enables the end users to configure individual parts of 3D assembly in a regular browser, and thus provides an effective tool to collect the customer's voices in e-commerce. The second system realizes mass customization for car interior design. Online ergonomic evaluation is conducted based on the interactions between a digital human mimicking the user and the design model. Finally, an Internet-based design review system is implemented. It enables synchronous communications between a designer and people involved in the change process with no access to CAD. These prototypes demonstrate the practicality, flexibility, and versatility of the WCV in integration with other proprietary software tools using a variety of platforms like ASP framework, Java-based technology, and Windows C/C++ applications. This work shows that the WCV is an interfacing technology, which facilitates 3D information sharing for most product-centric activities in a simple and cost-effective manner.

Keywords: Product development; CAD; Collaborative visualization; 3D viewing; The Web

1. Introduction

Due the to the ever-increasing economic globalization, collaborative product development (CPD) has emerged as an effective means for the medium and small-sized enterprises (SMEs) to remain competitive in the global market. They must assure their core competence by properly leveraging and synergizing external resources [1]. Hence, close collaborations with customers, suppliers, and other business partners become imperative for most companies to meet time-to-market and reduce product development costs. This trend is particularly common in the Asia-Pacific region, where most companies are fragmented into niches but cooperating in a form of vertical disintegration [2].

The primary goal of CPD is to integrate knowledge, technologies, and resources among all the participants to quickly respond market and fulfill customer needs. Successful deployment of CPD requires managerial as well as technological innovations in organization, operational process, and information technology [3]. Early involvement of suppliers and customers has been well-recognized as a key factor in new product development [4–6], particularly during the design activities. Compared to traditional supply chain management, the design chain management involves higher task uncertainty, more complex information (often in an incomplete form) [7], and new buyer–supplier relationship [8]. Thus a new paradigm is needed within the total supply network.

Recent progress in information technologies (in particular the Internet) enables efficient cooperation, communication, and coordination in CPD involving the team members geographically dispersed. There has been a significant growth in collaboration software products and services, which perform a variety of tasks, from scheduling, teleconferencing, project management, to data management, information exchange, and applications integration. As an infrastructure for product information repository at its early stage [9], the Web has

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[*] Corresponding author. Tel.: +88 635 742 698; fax: +88 635 722 685.
E-mail address: chchu@ie.nthu.edu.tw (C.-H. Chu).

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evolved into a working desktop equipped with all kinds of functions. Collaborative computing software has also shifted from facilitating the commerce activities in traditional supply chain like procurement, logistics, and scheduling [10–12], to expediting sophisticated interactions among product designers [13–15] as well as with end customers [16,17]. However, the technology of the Internet-based product design so far has been more concerned with collaborative CAD tools [18–20] and the Web-based PDM systems [21–23]. They correspond to design construction and design management, respectively. Fewer efforts have been focused on how to integrate the customer's voices or other stakeholders who have no access to design tools (or most of the time have no such needs), such as marketing staff, services people, and small/medium suppliers. Still, involvement of these people in the development process is important. To overcome this deficiency, new technologies have been developed for distributing product information among people without proprietary or high-end software systems. One promising technology is the Web-based collaborative visualization (WCV) (or 3D Web viewing), which enables the user to visualize, annotate, and control 3D design model interactively over the Internet. Commercial software tools such as AutoVue$^{\text{TM}}$ [24], SpinFire$^{\text{TM}}$ [25], and Hoops3D$^{\text{TM}}$ [26] have been successfully deployed in many industrial applications as described in the later section.

This paper expands use of the WCV further into more complex situations in distributed product development. Three novel applications are developed using this technology. They demonstrate the variety and practicality of the WCV as an interfacing technology for a range of product collaborations. First, the end customer is able to change the configuration of each component in 3D assembly and see the resulting assembly in real time with a regular browser. This product configurator facilitates consumer preference collection in B2C e-commerce. In the second system, the user performs online evaluation for the driving comfort with a digital human and interactively adjusts the car interior design based on the evaluation result. This system realizes the concept of online mass customization. Finally, an Internet-based framework is implemented for synchronous collaborations with a focus on design change review and notification. It validates peer-to-peer design collaborations between CAD and a 3D viewer in a preliminary manner. The advantages of the WCV are concluded from the implementation results. This work explores novel applications of the WCV tools on the product-centric activities, and thus demonstrates its practicality as well as versatility in design knowledge dissemination and information sharing in CPD.

2. Introduction to collaborative visualization

The term *collaborative visualization* originally refers to a subset of computer-supported cooperative work (CSCW) applications in which control over parameters or products of the scientific visualization process is shared [27]. The visualization process generally consists of a series of filtering raw data that generate the desired resolution and preserve contents of interest. A mapping step is required to render the result into a graphical form, and create an image, animation, or other data formats. Fig. 1 shows a simplest form of collaborative visualization application [28] with multiple participants. Only the one creating the data has direct interaction with the visualization process, and the other are limited to passive viewing of the results. The participants may exchange feedback using other collaboration tools such as email, MSN, whiteboard, or teleconferencing.

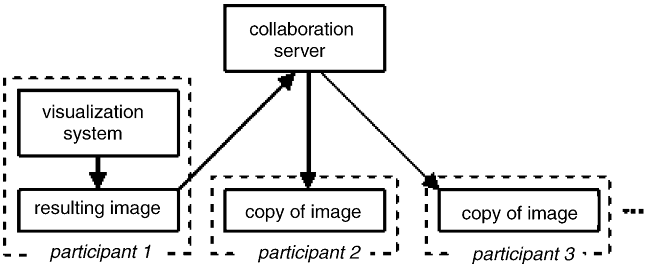


Fig. 1. Schematic of a simple collaborative visualization system [28].

This research focuses on collaborative visualization capabilities in distributed product development. Within this context, the product data (normally CAD model) is converted into a light-weighted and more universal file format for easy transfer and distribution over the Internet. A common industrial standard is the STL format [29]. An STL file represents an object as a mesh of connected triangles. Commercial collaborative visualization tools may have their proprietary file format, but most of them adopt the mesh model as a basis. A well-known geometric algorithm, Delaunay Triangulations [30], has been available for generating a mesh model with a controllable degree of approximation to the converted object. In addition, the common graphics libraries from fundamental OpenGL to high-level modeling schemes like Java3D, VRML, and X3D all support geometric manipulation and graphical rendering of a mesh model in 3D space. This opens up wide applications of collaborative visualization in heterogeneous IT platforms, particularly the Internet environment. There have been many deployments of the WCV in industries, described as follows:

- *Data management*: one of the early needs of collaborative visualization is to provide viewing capability for complex CAD drawings, particularly 3D models. Many commercial PDM/PLM systems (SmarTeam$^{\text{TM}}$, TeamCenter$^{\text{TM}}$, Windchill$^{\text{TM}}$, Agile$^{\text{TM}}$, and eMatrix$^{\text{TM}}$) provide the so-called CAD viewer for effective document management. Fig. 2 captures a screenshot of such a viewer embedded in a PDM tool. A project manager can thus access to the design data, at least visually, without opening up any design tools. However, these PDM-embedded tools fulfill the needs of design review and information sharing only to a limited degree. They are neither open enough for customized applications from the implementation aspect nor accessible to end customers on the other hand.
- *Sourcing*: to identify qualified suppliers is crucial for distributed product development on a global basis. Potential suppliers must obtain enough details regarding the design being outsourced in order to determine whether the part can be made by them and whether to place a quote on it. However,

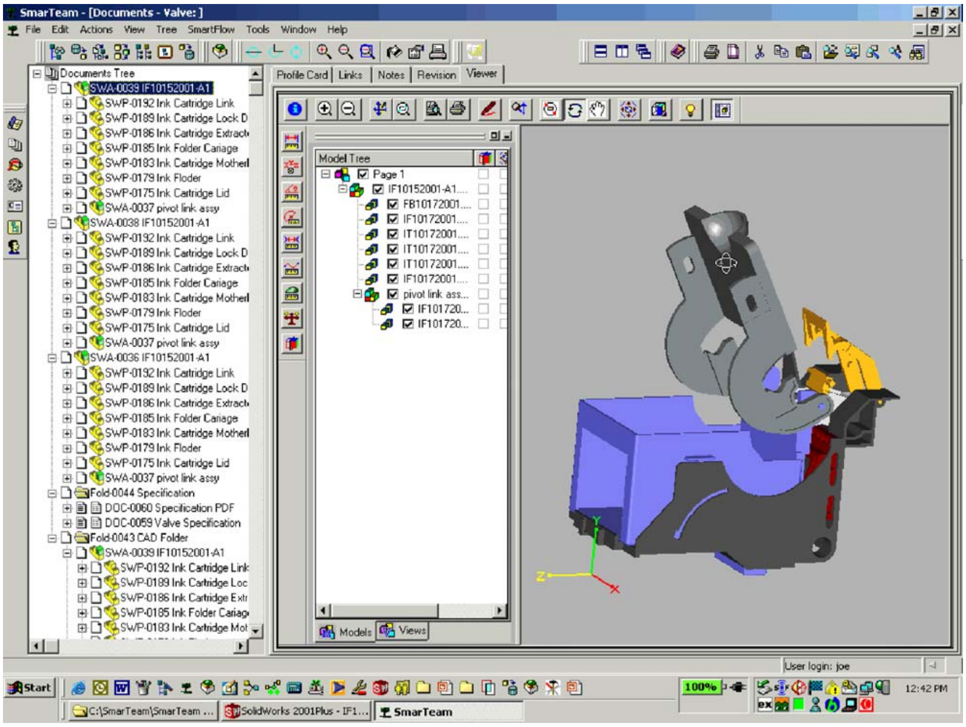


Fig. 2. Integration of CAD viewer in a PDM system (http://www.smarteam.com/).

they should not gain access to any design know-how before an official contract is finalized with obligations enforced. The collaborative visualization technology provides a feasible solution in this situation. It converts a CAD model into the mesh model with a controllable approximation to the original design data. The conversion excludes essential design information. As a result, a company can attach such a simplified model to an electronic RFQ (Request for Quote) and send it over to possible suppliers without risking leak of the proprietary information.

- *3D catalogue*: text data, photo, animation, and video clip are not enough for modern customers during their e-commerce activities. Many companies [31–33] start to offer the Internet-based 3D product catalogues in their websites. Fig. 3 illustrates an example of bicycle component. The users can visualize the product in 3D space interactively with simple graphical manipulations, enhancing their satisfaction in online shopping. An enterprise user may want to download the part model and estimate its compatibility in the assembly being designed.
- *After services*: collaborative visualization also finds useful applications in the after service activities such as online DIY (Do-It-Yourself) product manuals [34] and maintenance instructions [35]. These ‘paperless’ documents save material cost, are downloadable everywhere, and can be updated at any time without additional costs. It is considered a better tool for product data communication.

Fig. 3. Online 3D catalogue of bicycle parts (http://fishing.shimano.co.jp/body/3D_new).

3. 3D product configurator

Customer voices are essential to the success of product development, from the front-end customer needs collection to feedback of the product in use. Mass customization has become an imperative in the market. The end user often wants to configure, if not design, the product with individual preferences, and better in the cyber space using simple GUI’s. The Internet has emerged as an enabling medium for achieving this goal. In fact, companies have been offering online product configuration for years (Dell Computer is the most famous example). However, the customers are only allowed to choose product specs in most cases, without real-time updates in the product appearance or overall shape. Some online shopping sites use 2D images for showing

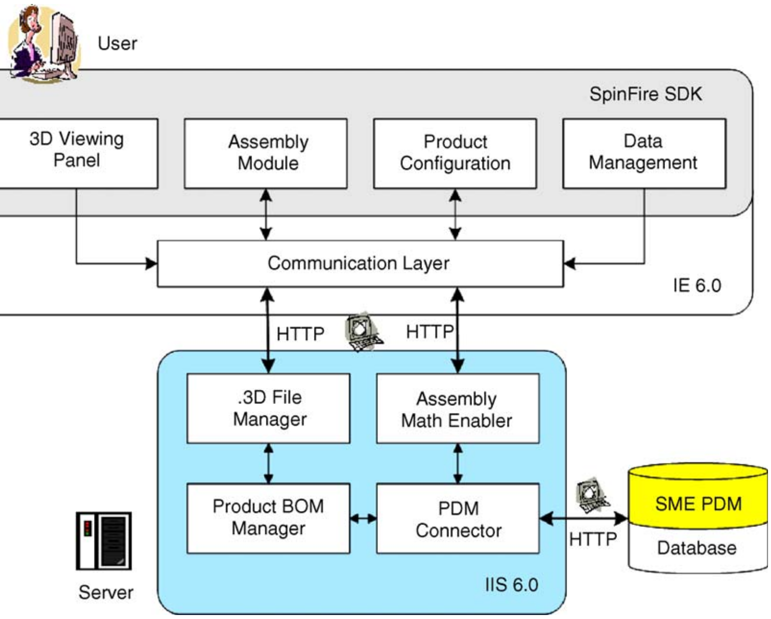


Fig. 4. System framework of the 3D product configurator.

customer's configurations, but this may not be effective when the product styling (shape, color, and appearance in 3D space) is a key factor that influences the purchase decision. There is a need of practical IT tools with which the online user can readily interact with 3D product during the e-commerce activities.

This work develops an online 3D product configurator to fulfill the need. It contains three major components: SpinFire^{TM} collaborative visualization utilities, an applications server, and a PDM system. Fig. 4 shows the system architecture. These components are integrated with the HTTP protocol in the ASP^{TM} framework. The viewing application is embedded in an IE 6.0 browser that allows the end user to access the system over the Internet. A command panel provides various 3D graphical functions, implemented with JavaScript API's in SpinFire^{TM}, for the user to interact with the product. A product assembly hierarchy allows the user to configure the product by selecting various configurations for each component, as shown on the right side of the GUI in Fig. 5. The PDM system, SME PDM [36], stores all the product-related information including BOM (Bill of Material), each component configuration, the full configuration, and the user preference. The applications server, Microsoft Internet Information Server (IIS) 6.0, manages, dispatches, and controls the information flow between the PDM system and the GUI at the front end. It also works as a Web server in the current prototype design.

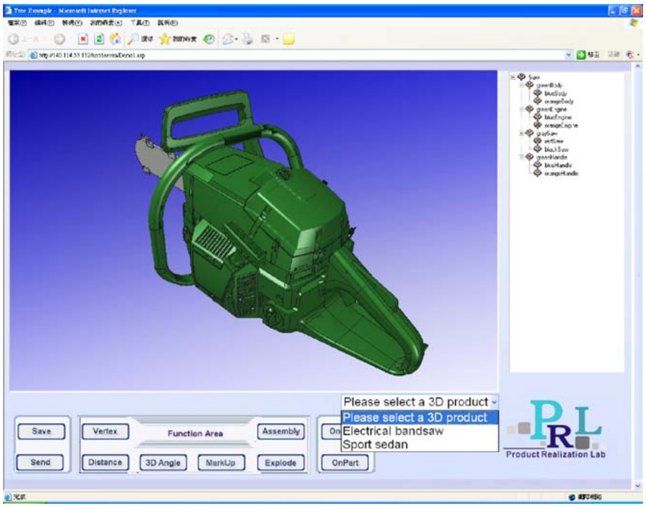


Fig. 5. GUI components of the 3D product configurator.

A typical use scenario is described as follows:

- The user establishes an HTTP link to the system and chooses a product for configuration from a drop-down menu. A sport sedan is chosen in the case shown in Fig. 6(a).
- The default blue car body is not attractive to the user, who thus decides to see the styling effect with a white body. The system instantly displays the corresponding product (see Fig. 6(b)).
- Fig. 6(c) shows that the user may want to rotate, zoom, and even disassemble the product for detailed evaluations.
- Finally, the user may configure the car as the combination of a gray wheel, a yellow car body, a gray windshield, and a white seat, as shown in Fig. 7.
- By clicking the button on the panel, the product configurations are sent over to and stored in the backend database.

In addition, the user can express special requests with respect to individual components using the 3D markup function provided by the system. The server transfers the product configuration along with the markup notes residing in an XML document over to the PDM. Fig. 8 shows the corresponding XSLT. This information will be automatically recognized, associated to the corresponding component, and later saved in the database, after the document arrives and gets parsed at the

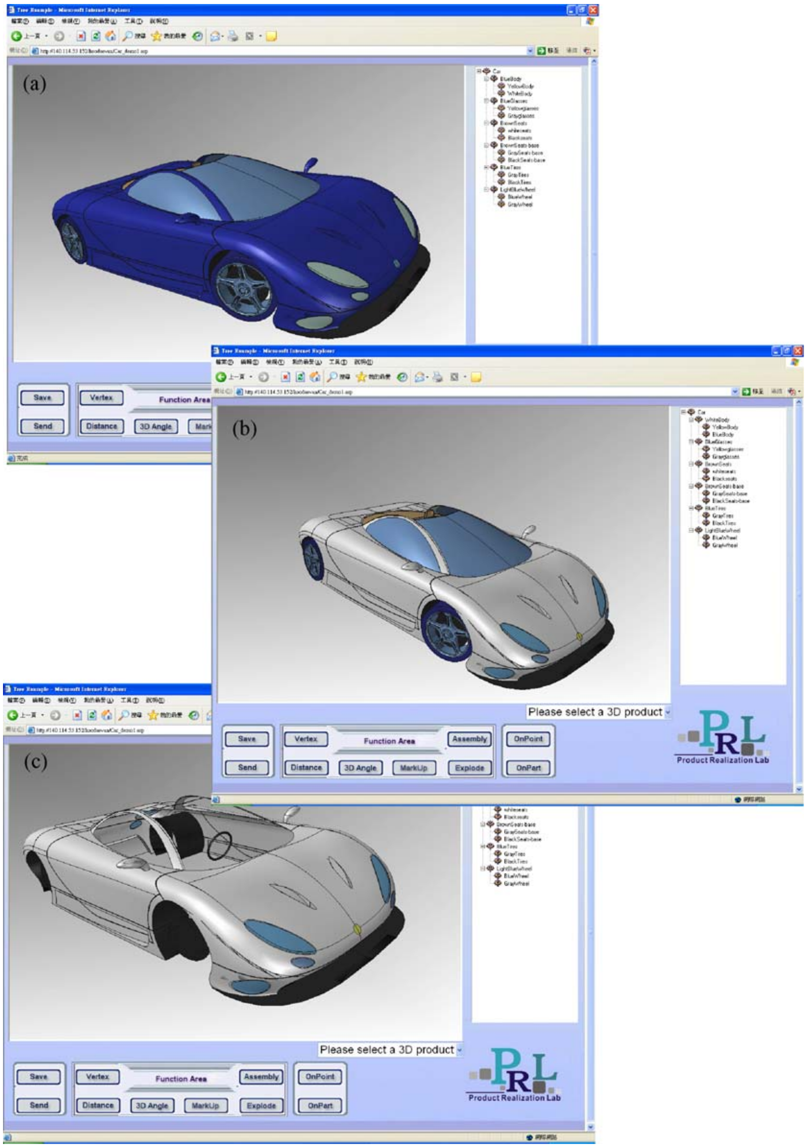


Fig. 6. The use scenario for configuration of a sport sedan.

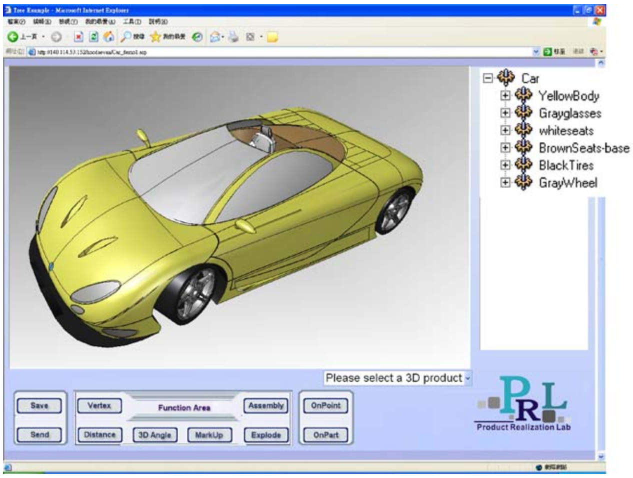
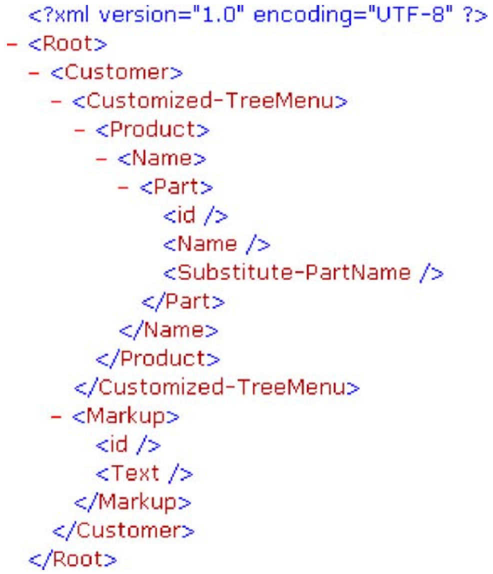


Fig. 7. The final product configurations.

backend. Thus, the product preferences input by the customer are quickly and effectively collected through the Web, enabling online mass customization.

4. Ergonomic evaluator for mass customization

The online ergonomic evaluator introduced in this paper consists of four major software components [37]: 3D visualization module, posture generator, ergonomic evaluation engine, and applications server, as shown in Fig. 9. A 3D viewer, SpinFire^{TM}, serves as an integral part that interacts with the user and produces necessary geometric data for ergonomic evaluation. The posture generator contains several human templates corresponding to various postures constructed from the body motion data. These templates are stored in Microsoft Excel^{TM} spreadsheets at the backend. Each one describes a sequence of coordinate transformations for the body parts



```
  <?xml version="1.0" encoding="UTF-8" ?>
- <Root>
  - <Customer>
    - <Customized-TreeMenu>
      - <Product>
        - <Name>
          - <Part>
              <id />
              <Name />
              <Substitute-PartName />
            </Part>
          </Name>
        </Product>
      </Customized-TreeMenu>
    - <Markup>
        <id />
        <Text />
      </Markup>
    </Customer>
  </Root>
```

Fig. 8. XSLT for the product configuration and markup data.

involved in the posture generation. A full-scale 3D digital human is produced and controlled based on these spatial relationships using the mathematical and graphical functions provided by SpinFire™ API's.

An evaluation program residing at the backend estimates the comfort for different sitting poses with a two-dimensional statically biomechanical model. The formulae of moment/force calculations for critical joints of the upper limbs including shoulder, elbow, and wrist are expressed in Excel™ spreadsheets. The posture generator provides the pose data required in the evaluation through a direct binding between two Excel™ threads. The engine then sends the calculation result back to the user en route the server. A socket thread is running on the client side and pending until receipt of this response. This system adopts Apache Tomcat™ as an applications server, which dispatches the requests initiated from the client via an IE browser, to the inference knowledge bases (posture generator and ergonomic evaluation engine). JXL™ offers an interfacing technology for the data transfer between the client browser and the backend.

A use scenario demonstrates online ergonomics evaluation of car interior design using the system. First, the user remotely opens up a browser with the visualization program as a plug-in (ActiveX™) and starts an HTTP link to the server (see Fig. 10). The main page consists of three major portions: the left portion provides GUI's for inquiring the geometric information related to drive comfort, the center is a set of graphical functions, and the right module allows the user to adjust the pose of a digital human model with a set of predefined joint angles. A typical evaluation process comprises the following steps.

- Choose one interior design from the drop-down menu in the middle module.
- Create preferable 3D views of the design and store them as templates, see Fig. 11(a).
- Measure the dimensions related to the drive comfort resulted from the current interior setting using the graphical functions provide by the system.
- Estimate the corresponding joint angles, for example, the hip angle in Fig. 11(b).
- Query the resultant forces and the moments from the evaluation engine.
- The evaluation results are published in the browser as shown in Fig. 11(c).

5. Design change framework

Design change is a critical issue in product development. It is inevitable due to the iterative nature of the design activities.

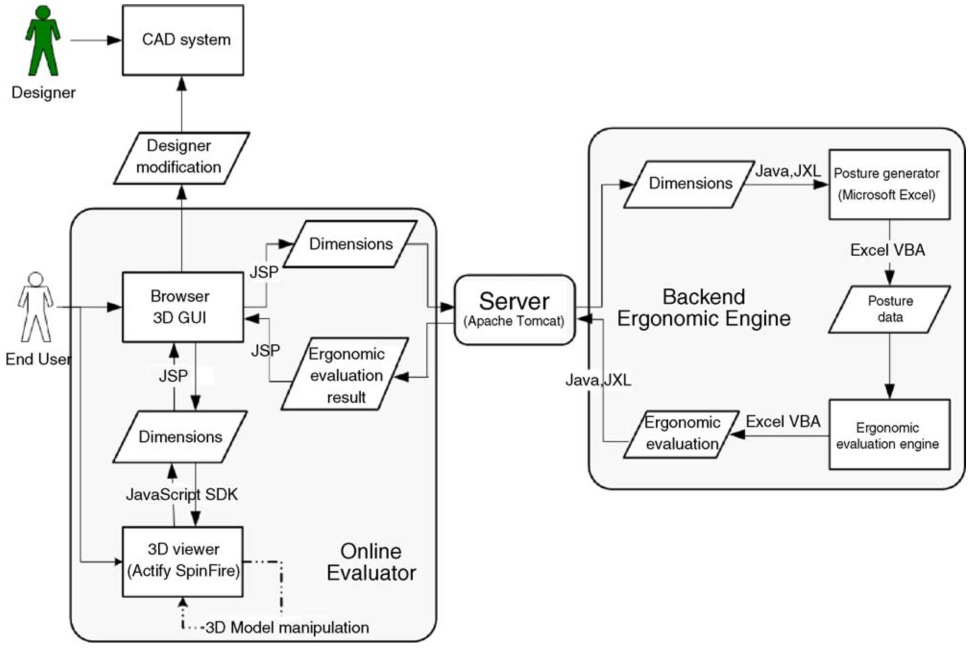


Fig. 9. Framework of the online ergonomic evaluator.

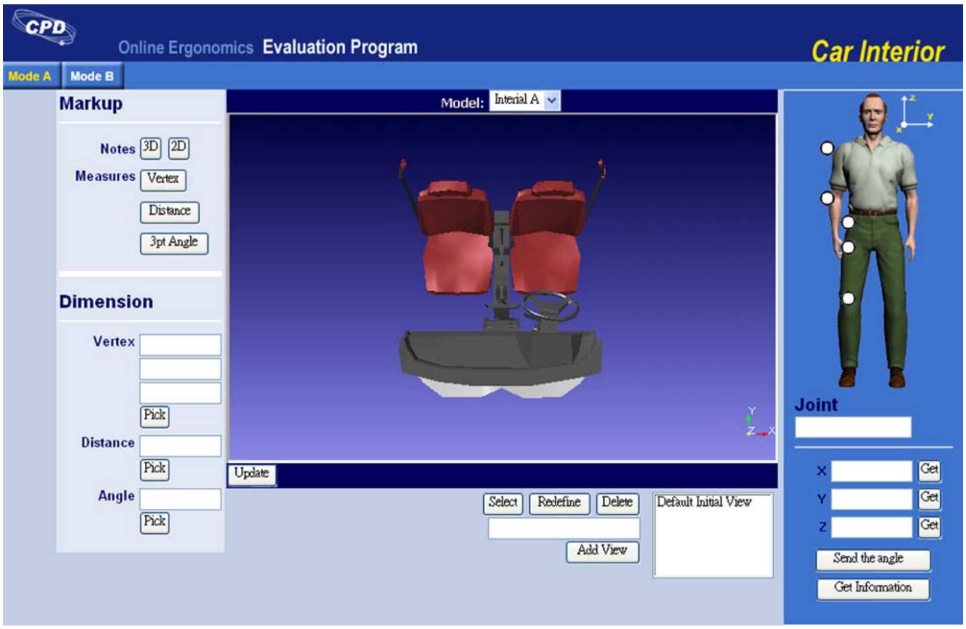


Fig. 10. Online ergonomic evaluator embedded in a browser [37].

Design change management can become quite complex in distributed engineering environment. Thus, companies need a well-conceived workflow and proper IT tools in order to reduce time and costs incurred in the change process. Sometimes people involved in a design change (can be an initiator, reviewer, coordinator, or subscriber [38]) may not have access to the necessary design data that help them make the right decision. One common reason is that the stakeholders other than the designer do not own appropriate software tools for visualizing or evaluating design modifications, especially for complex 3D product. The WCV also finds its good applications in this situation.

Fig. 12 illustrates the software framework of this system, which consists of three major components: Design Tool, Review Tool, and Backend Utilities. The central idea is to establish a synchronous connection between the design engineer and people without access to CAD tools using the WCS technology. A high-end CAD system, CATIA$^{\text{TM}}$ V5R13, is a center-piece of the Design Tool module. Other software components include Transmission Module, CAA V5 Utility Module, and Message Server, responsible for file transfer to Backend Utility, CAD utilities, and communication with Review Tool, respectively. CATIA$^{\text{TM}}$ provides an integrated development environment, CAA V5$^{\text{TM}}$ (Component Application Architecture) [39], with a set of C++ API's for customized applications. The SpinFire$^{\text{TM}}$ visualization program serves as the kernel of the Review Tool module. It works as a plug-in in a regular browser, Internet Explorer 6.0 in this case. This module receives the design data in the .3D format from Backend Utility, and performs messages exchange with Design Tool via a Message Client. Each task is handled with a C++ program. Backend Utility supports the file conversion from CATIA$^{\text{TM}}$ model (or other CAD files) to a proprietary light-weighted mesh model (.3D file). External applications can perform this conversion via SpinFire SDK$^{\text{TM}}$ in Visual Basic. The communication and data/message exchange between modules are handled with the Winsock programming method. The following sections describe two use scenarios in more detail.

5.1. Scenario 1

A design engineer has finished a 3D part design using CATIA$^{\text{TM}}$ show in Fig. 13(a). The engineer intends to have his/her manager approve the design or provide feedback. Clicking the transfer button initiates the transmission of the model over the Internet via a Winsock connection to Backend Utility located remotely. After receiving the CATIA$^{\text{TM}}$ model, a procedure call starts and invokes the SpinFire$^{\text{TM}}$ Server for file conversion to the .3D format. Next, the converted model is sent over to the manager via the same Winsock connection. Once the file has arrived intact, a MFC$^{\text{TM}}$ call is created and opens up SpinFire$^{\text{TM}}$ applications in Windows$^{\text{TM}}$. The manager can use the utility functions such as rotate, zoom, cross section, and measurement to examine the design in detail. Any feedback or discussions can be communicated between the both sides (Design and Review Tool) through a direct Winsock binding. For instance, the manager may consider the hole of the part too small, and thus ask for enlarging its size for another review. The engineer is notified with the request in real time, makes the modification accordingly, and sends the file back again en route the Server.

5.2. Scenario II

The conversion process of the .3D file discards important engineering attributes originally stored in a CAD model. This certainly reduces the effectiveness of collaborative visualization. For instance, a supplier may need to know the exact dimension and tolerance of some geometry of a part to have a

Online Ergonomics Evaluation Program

Biomechanical Information

Model Name: Interial A

	Compression	Shear Force
LSS1	385.703	1922.915

	Force	Moment
Elbow	210.014	-20.428
Shoulder	227.213	-58.02
Hip	303.751	-37.416
Knee	378.917	-139.4
Ankle	407.582	-207.389
Toe	416.5	-279.014

Fig. 11. A typical procedure for evaluating the drive comfort [37].

precise quote on it. Thus, it is necessary that the supplier can make a query about the dimensional information. SpinFire^{TM} provides a digital markup function for associating hyperlinks with certain geometric elements of .3D model. It serves as an interfacing mechanism that enables the communications between the designer and the reviewer. A use scenario consists of the following steps:

- The user clicks on a 3D tag containing the request of a dimension inquiry, and thus establishes an HTTP link to Design Tool.
- CATIA^{TM} Message Server parses the request.
- CAA V5^{TM} Utility Module makes a corresponding query from the CAD model via C++ API's and obtains the dimensional data.
- CATIA^{TM} Transmission Module sends the information as an XML document over to Review Tool en route Backend Utility.
- Review Tool atomically parses the XML and updates the display with the information.

In addition, a reviewing manager is likely to see tentative modification of some part feature for better design evaluation, and makes the final decision after several change iterations. To have real-time responses from the design engineer certainly helps reduce the review cycle time. For this purpose, we embed the modification command of a design feature in the HTTP link instead of the information query. Fig. 14 shows the corresponding screen shots for one review iteration. Note that the engineer is notified of the design request and can decide whether to perform the request (design feature change and information inquiry) or not.

6. Conclusions and future research

This paper has illustrated that the WCV provides useful tools for the information dissemination in distributed product development. Three novel prototypes were developed to demonstrate the versatile applications of the WCV. First, a 3D product configurator enables the end customers to choose among various configurations for each component, visualize the resulting product in real time, and interact with the product model. It lends a support to collecting the customers' voices and managing their product preferences on the Web. The second system allows the users to change the car interior design and estimate the corresponding drive comfort over the Internet. It provides a digital human model that mimics the driver at various levels of body size and shape. The users can interactively adjust the car design with respect to the human model until better ergonomic evaluation is attained. The last prototype implements a synchronous design review system which connects the people involved in the design change process but without access to proper CAD tools. This prototype enables them to visualize 3D product design and communicate with the design engineer. The user can inquire engineering attributes of the product and/or modify design features simply with a regular Web browser. Peer-to-peer design collaboration is thus realized.

These systems indicate a number of values added by the WCV in design practices. Perhaps the major value is that it serves as a non-proprietary interfacing technology for any product-centric activities in a product life cycle. It enables real-time interactions with 3D models through a Web-based collaboration environment, without the need of CAD or other sophisticated software. More importantly, the cost of the WCV tools and the development complexity is lower than those of CAD, providing small-to-medium sized companies a feasible solution for sharing 3D product data. As a result, the stakeholders, who could not access to the product model before, now have a practical tool for close collaborations with the core development team. In addition, this work expands use of the visualization tools by highlighting their novel applications on non-design tasks, such as mass customization and B2C e-commerce. Finally, these prototypes demonstrate the flexibility and versatility of the WCV in integrating with other

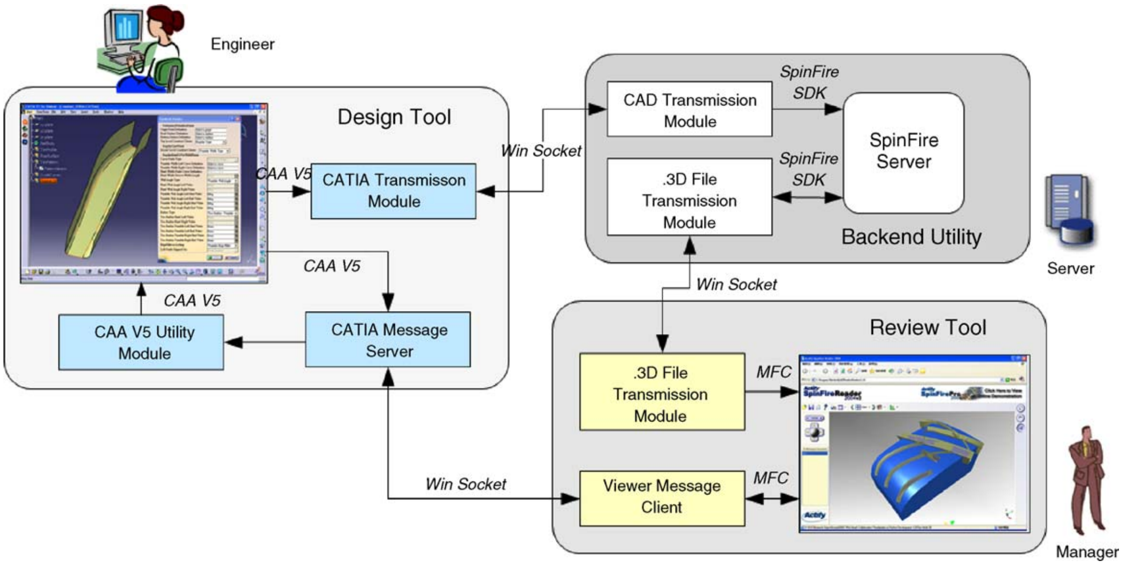
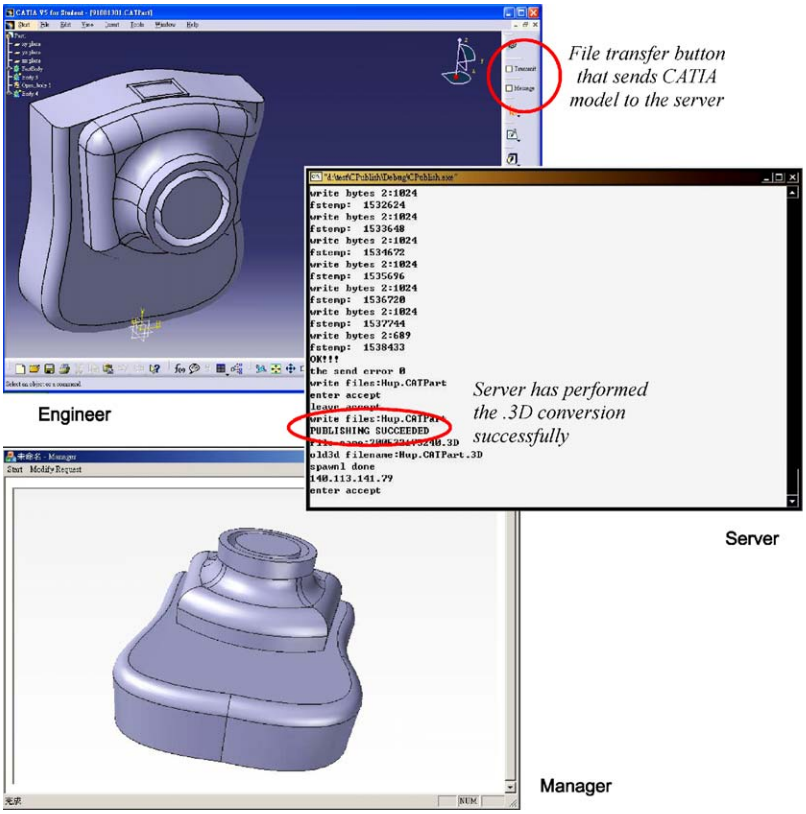


Fig. 12. Software framework of the design change system.

proprietary software tools using a variety of platforms like ASP framework, Java-based technology, and Windows C/C++ applications.

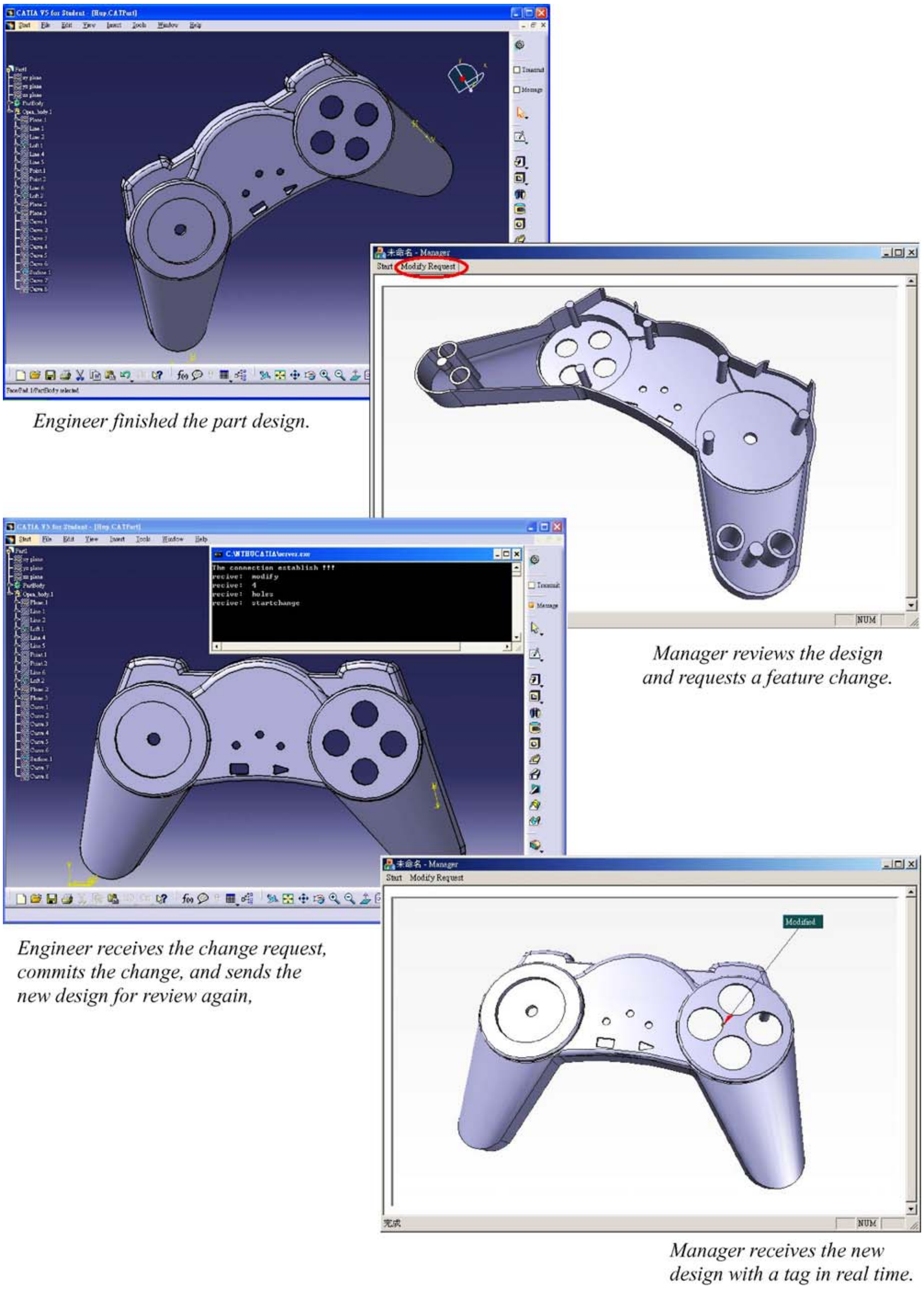
However, the progress of the WCV is still at a premature stage. Possible enhancements include:

- *Levels of detail* (LOD): depending on the role and individual requirements, each collaborator in distributed product development should access to the product information at various levels of detail [40], even the way of visualization and presentation has to be adapted to specific applications. For example, a component supplier is not supposed to see the complete assembly other than the part being outsourced to it and the interfaces to the other parts. The visualization model running in a wireless device should contain graphical data in a more compact form than that of a desktop PC. Therefore, the



```
write bytes 2:1024
fstemp:  1532624
write bytes 2:1024
fstemp:  1533648
write bytes 2:1024
fstemp:  1534672
write bytes 2:1024
fstemp:  1535696
write bytes 2:1024
fstemp:  1536720
write bytes 2:1024
fstemp:  1537744
write bytes 2:689
fstemp:  1538433
OK!!!
the send error 0
write files:Hup.CATPart
enter accept
leave accept
write files:Hup.CATPart
PUBLISHING SUCCEEDED
file name:2005[illegible]240.3D
old3d filename:Hup.CATPart.3D
spawnl done
140.113.141.79
enter accept
```

Fig. 13. First scenario of the design change framework.



Engineer finished the part design.

Manager reviews the design and requests a feature change.

Engineer receives the change request, commits the change, and sends the new design for review again,

```
C:\NTHUCATIA\server.exe
The connection establish !!!
recive:  modify
recive:  4
recive:  holes
recive:  startchange
```

Manager receives the new design with a tag in real time.

Fig. 14. Second scenario of the design change framework.

WCV technology must provide multi-resolution representations, both semantically and graphically, to fulfill these needs.

- *Deformable model*: the development of WCV emphasizes more on viewing effects. To offer the real-time modification capability is highly valuable in certain applications, e.g. with this functionality a reviewer can adjust the size or position of some design feature for product evaluation when the network is not available. A marketing person may need to change the shape or appearance of a product and demonstrate the effect immediately without CAD software or any connections to it. The FFD (free-form deformation) method provides a solution for this.
- *Enabling multimedia data*: to integrate multimedia data (video, audio, telephony, and other content-rich information) with the WCV tools can significantly enhance the Internet browsing capability by offering a sophisticated interactive environment.

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Chih-Hsing Chu attended National Taiwan University and received his BS and MS from Department of Mechanical Engineering. He received his PhD in mechanical engineering at the Laboratory for Manufacturing Automation, University of California at Berkeley, USA. His project work at Berkeley was focused on Internet-based design and manufacturing. He worked as a web applications engineer at RedSpark, an Autodesk Venture, on development of Web-based collaboration software. His past work experiences include Research Intern at DaimlerBenz AG, Stuttgart, Germany, and Technical Consultant for STANDFORD Machinery, Taoyuan, Taiwan. Prior to joining National Tsing Hua University in 2002, he was on the faculty of Industrial and Systems Engineering Department, Virginia Tech, Blacksburg, USA. He also worked as a visiting researcher for 1 year at the Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen, Germany. He was an invited scholar at CREDITS Center, Sungkunkwan University, Korea, during the summer of 2005. His research interests include product development, collaborative design, design chain management, and CAD/CAM. He is a member of the SME, ASME, PDMA, and SCC.

Ching-Yi Cheng is a graduate student in College of Computer Science, National Chiao Tung University, Hsinchu, Taiwan. He received his BS degree from Department of Computer and Information Science of the same school in 2005. His research interests include computer graphics, 3D animation, and distributed computing.

Che-Wen Wu is a graduate student in College of Computer Science, National Chiao Tung University, Hsinchu, Taiwan. He received his BS degree from Department of Computer and Information Science of the same school in 2005. His research interests include computer networks, embedded systems, and distributed computing.