Distributed rapid prototyping – a framework for Internet prototyping and manufacturing

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Abstract
This paper focuses on the development of a distributed rapid prototyping system via the Internet to form a framework of Internet prototyping and manufacturing for the support of effective product development. The proposed methodology is targeted at a wide audience using a disparate range of computer systems to access remotely located rapid prototyping facilities via the Internet for prototype fabrication. The methodology is useful for both educational research for teaching evolving rapid prototyping technologies and remote scientific visualization. This approach is based on the merger of object-oriented modular software architecture and client server communications for the remote control of rapid prototyping hardware (called fused deposition modeling) via the Internet. Other Web tools are used to allow the remote user to have higher interactivity with the server applications that have a direct link with the front-end terminals controlling the rapid prototyping hardware.

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Introduction

Manufacturing and design technologies are gradually gravitating towards Internet integrated technology to cope with emerging challenges such as the need for shorter time to market, reduced lead time in the supply chain of new products, reduced cost and higher quality. The merging of Internet and manufacturing technologies has resulted in the bridging of the gap between engineering technology (such as rapid prototyping hardware system) and the information system to enable the remote control of engineering resources. As such, geographical constraints can be overcome. In order to realize this concept, more advanced support software such as Java (Siyan *et al.*, 1997) is being developed to integrate manufacturing technology (Jacobs and Prioleou, 1996) with the Internet so that various manufacturing processes can be controlled online. In particular Java has made it possible to integrate interoperable, modular and extensible distributed application together to monitor and control a physical environment (Grimaldi *et al.*, 1998). As to date, there are a number of researches in the application of Internet infrastructure for engineering purposes (Tan *et al.*, 1998; Brown *et al.*, 1998). Most of the research work is mainly focused on the utilization of this technology for virtual reality (Toung *et al.*, 1997) and for faster and effective communications only. However, these approaches cannot fully address the real life engineering problems where real models have to be formed as a result of synthesis of time and resources and where the global market competition of supplying better quality products is very crucial.

The concept of distributed systems has long been widely used in the manufacturing and design industries to facilitate manufacturing and product development operations. However, traditional distributed systems are hardwired and limited to a particular location and resources and accessibility is limited to a particular location only. Recently, there is considerable interest in the area of Internet enabled distributed systems. Examples of these works include the application of the Internet infrastructure for virtual reality (Broll, 1997) and online measurement (Grimaldi *et al.*, 1998). The proposed methodology is different from others in that it focuses on the formation of physical models online via the Internet when a geographical distance separates the end user and the physical hardware. This approach is applicable for a wide spectrum of end users due to its interoperability, modular functionality and scalability. The targeted audiences include users in the educational sectors who can use the framework for online teaching of new manufacturing technology such as rapid prototyping technology, and secondly for parties involved in product development who can use the facility to view and analyze the prototyping concurrently. In addition, professional prototyping centers can serve as rapid prototyping service providers for low volume manufacturing organizations to utilize the rapid prototyping facilities. The potential applications are numerous and especially so as this technology advances and new challenges arise.

Distributed rapid prototyping via the Internet

In recent years, new technologies have emerged to facilitate the rapid prototyping of 3D CAD models so that complex and aesthetically shaped prototypes can be formed both for end use and for the analysis of design and manufacture as a part of the product development process. For efficient product development and fast return on

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investment, there is a need for a rapid product development cycle that is made possible by decreasing the cycle time for product design and analysis. Product design in the product development cycle is the most critical phase where iterative prototyping is required for various analyses. Traditional prototyping is very slow and ineffective in resources utilization. Consequently, new rapid prototyping technologies have emerged in the last few years and most of the cost-effective prototyping nowadays is carried out by rapid prototyping technique. Complex and aesthetically shaped models can be rapidly fabricated using these rapid prototyping technologies, which resulted in their extensive use by design and manufacturing organizations. However, no technology can stay successful in its stand-alone form in a dynamic and competitive global market. The same applies to the rapid prototyping technology as well. In order to enhance the accessibility of available rapid prototyping services to a broader community of users (organizations or individuals) involved in the product development, research or scientific visualization process either for educational or commercial purpose, an approach has been developed so as to integrate the rapid prototyping technology with the Internet. In this approach, use of interoperable, modular and platform independent application has been developed to integrate the rapid prototyping technology with the Internet infrastructure for integrating the global resources online.

This current effort aims at providing manufacturing facilities to geographically separated partners in low and high volume manufacturing organizations, research institutes and others involved in the field of product development or scientific visualization using rapid prototyping technologies by means of remote access via the Internet. The methodology is based on the principle of Internet based distributed system and is commonly termed as Internet Manufacturing (IMAN). The approach focuses on various aspects of manufacturing and design literature. Firstly, geographically disintegrated resources can be synthesized online for real-time manufacturing. Secondly, geographically separated product development team members can work concurrently for the new product development process. Thirdly, aesthetically shaped complex prototypes can be fabricated remotely for the purpose of rapid tooling, scientific visualization and analyses. Through IMAN, commercial organizations can be engaged in prototype development and customization through a professional rapid prototyping center without the need for their own investment for setting up costly prototyping facilities.

Brief description of IMAN system

The Internet based distributed rapid prototyping architecture is a common client server model, which centers on object-oriented application model using Java and common Web tools. The four basic components of the approach are:

1. Internet: as the standard communications infrastructure;
2. Java: as the object-oriented implementation language both for client and server applications;
3. Other Web tools (e.g. Virtual Network Computing, Web Cam): as an access and configuration tool for a remote server system; and
4. Fused Deposition Modeling (FDM): as the rapid prototyping hardware.

A major benefit of choosing Java (Siyan *et al.*, 1997) is the achievement of portable and object-oriented software (i.e. the developed application is completely platform independent, easy to maintain and extend). Java implementation relies on native methods and driver libraries and the non-portable parts relate only to interface bus drivers of the rapid prototyping hardware. In addition, it delivers a platform neutral framework for the construction of the human computer interface (HCI) (Chen *et al.*, 1998).

Network speed is an important factor to be considered in order to fully harness the advantages of IMAN. With the current trend towards high-speed network development, the IMAN system performance will be better realized with the increasing high-speed network facilities. At this point the mechanism is kept simple to realize a sufficient performance level under the current commercial network links available. Nevertheless it has been ensured that the current architecture is general enough not to limit the potential application areas in the future with the continuous development of a high-speed network such as “Very High Speed Backbone Network Service” (vBNS) (IEEE Spectrum, 1998) that has higher bandwidth capability.

Though the concept has been developed using FDM, the same concept is applied to other rapid prototyping technologies such as Selective Laser Sintering (SLS), Stereo-Lithography Apparatus (SLA) and Laminated Object Manufacturing (LOM). A major benefit of choosing FDM as our test tool for IMAN is the capability of FDM to

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make a complex and aesthetically shaped prototype and also because of its open architecture.

A general architecture (see Figure 1) of IMAN consists of a set of server and front-end terminals (only one is shown in Figure 1). The client and server applications are linked to one another via the Internet. In addition, other common Web tools, such as Web cam and video conferencing software that run independently of each other, are also incorporated in the rapid prototyping center. The client interface is also designed to be very transparent and user friendly so that the user does not need to download and install extra plug-ins to run the application. A general-purpose machine such as Win9x/NT or Sun Solaris with common Web tools installed will be sufficient to support IMAN.

A client interface is also designed to host, on demand, the human computer interface required for configuring and monitoring the remote prototyping system.

Object-oriented architecture of the IMAN system

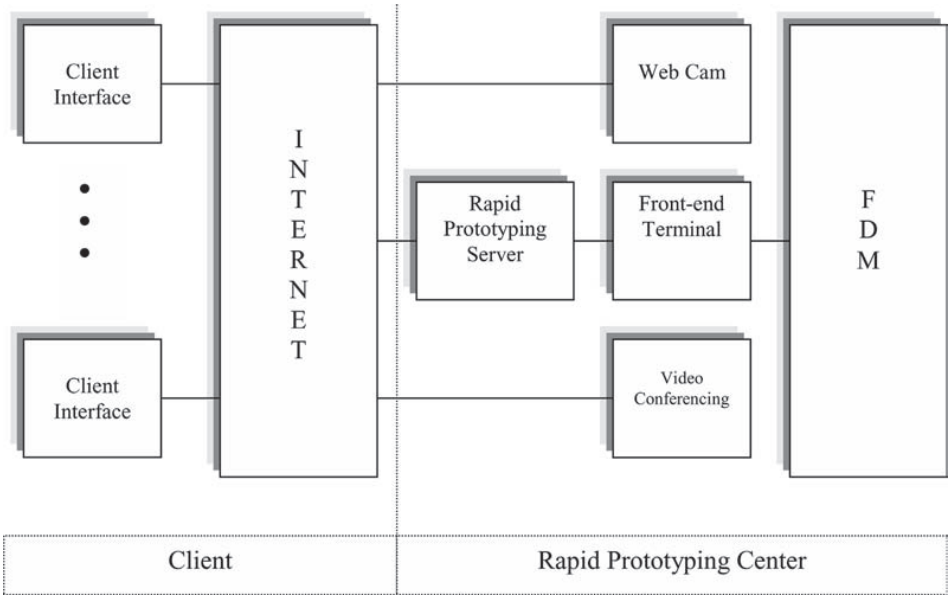
A distinctive feature of the approach is the adoption of object-oriented software architecture for the development of the IMAN system on both the client and server side. The core module of client server interaction has been developed using Java and is completely object-oriented and platform independent. Java offers versatile, clean and type free object-oriented mechanisms for building the system. It also provides client/server-networking facilities for Internet based communications.

The IMAN system is a three-tier client server architecture consisting of the client interface, server applications and front-end terminal applications dedicated to the rapid prototyping hardware. The front-end terminal is directly connected to the rapid prototyping hardware and is dedicated to the hardware for its locally intensive data manipulation process.

The distributed rapid prototyping system consists of two major Java components, namely, the client application and server application. The client application has been developed using the Java Abstract Window Toolkit (AWT) package that furnishes the graphical user interface (GUI) services. During its lifetime, the client interface interacts with the server partner application running on the server (see Figure 2). The server component of the distributed rapid prototyping system relies on Java object-oriented mechanisms and on the capability of directly interfacing with the native methods of a standard interface driver library of the rapid prototyping hardware.

In reality, as one can see from Figure 2, an application is structured into two sub-components, namely, a Java Server component written in Java and listener threads within the server program. The server component is multi-threaded. It constantly runs and listens for a client asking

Figure 1
IMAN framework on the Internet



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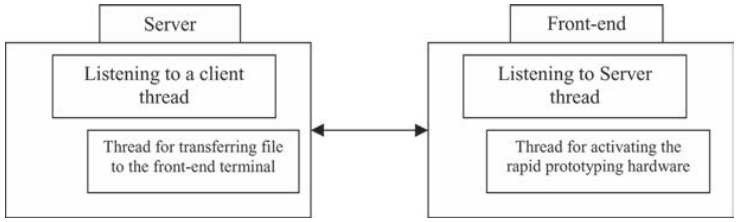
for a connection to a port number representing a particular client instance to form a socket connection for bi-directional interactions with the client. The Internet protocol such as the transfer control protocol and Internet protocol (TCP/IP) is implemented for data transfer process. The receiver server socket is synchronized for each client instance. Until a client instance is completed, no other client's request will be processed.

From the viewpoint of the client application, the socket connection is active only for data transfer and invocation of the rapid prototyping hardware. Other audio and visual feedback from the remote location where the server and rapid prototyping hardware are resided can be obtained by the use of Web cam and video conferencing (see Figure 3). Normally, only one single client connection can exist at any one time to a given port. This complies with the constraint that only one single client request can be processed for using a given set of rapid prototyping hardware at any one time. Interference problems due to concurrent accesses to a shared bus of the rapid prototyping hardware can be handled by mutual exclusion mechanisms (synchronized methods). At the termination point of previous client operation, the socket connection is closed and the server can accept a new connection on the same port, thus starting a new instance of client server connection and so forth.

In a slightly different scenario, multiple clients could be allowed to watch the same fabrication process for discussion and analysis. This facility may be required in a distributed system where the active process needs to be instantaneously viewed by several people at different client stations for concurrency (Roy and Bharadwaj, 1997; Yoshimura *et al.*, 1998).

The client interface is designed to enable the client to interact with the server transparently. Clients are required to have common Web tools such as Netscape Communicator browser. The use of server component and other Web tools to run independently isolates the two kinds of tasks in the rapid prototyping center. These are critical tasks such as data transfer to the front-end terminal via the server and non-critical ones such as video conferencing and concurrently viewing of the rapid prototyping status. This kind of isolation frees up the burden of the server to handle extra loads for these lower value-added jobs while concentrating more on other server and front-end terminal intensive tasks such as data conversion to machine format with the QuickSlice. Access to the QuickSlice is synchronized for one client at a time. As a security measure the distributed rapid prototyping system is designed to disallow multiple user-access to a single or a limited number of physical hardware at anyone time.

Figure 2
Client, server and front-end terminal interaction

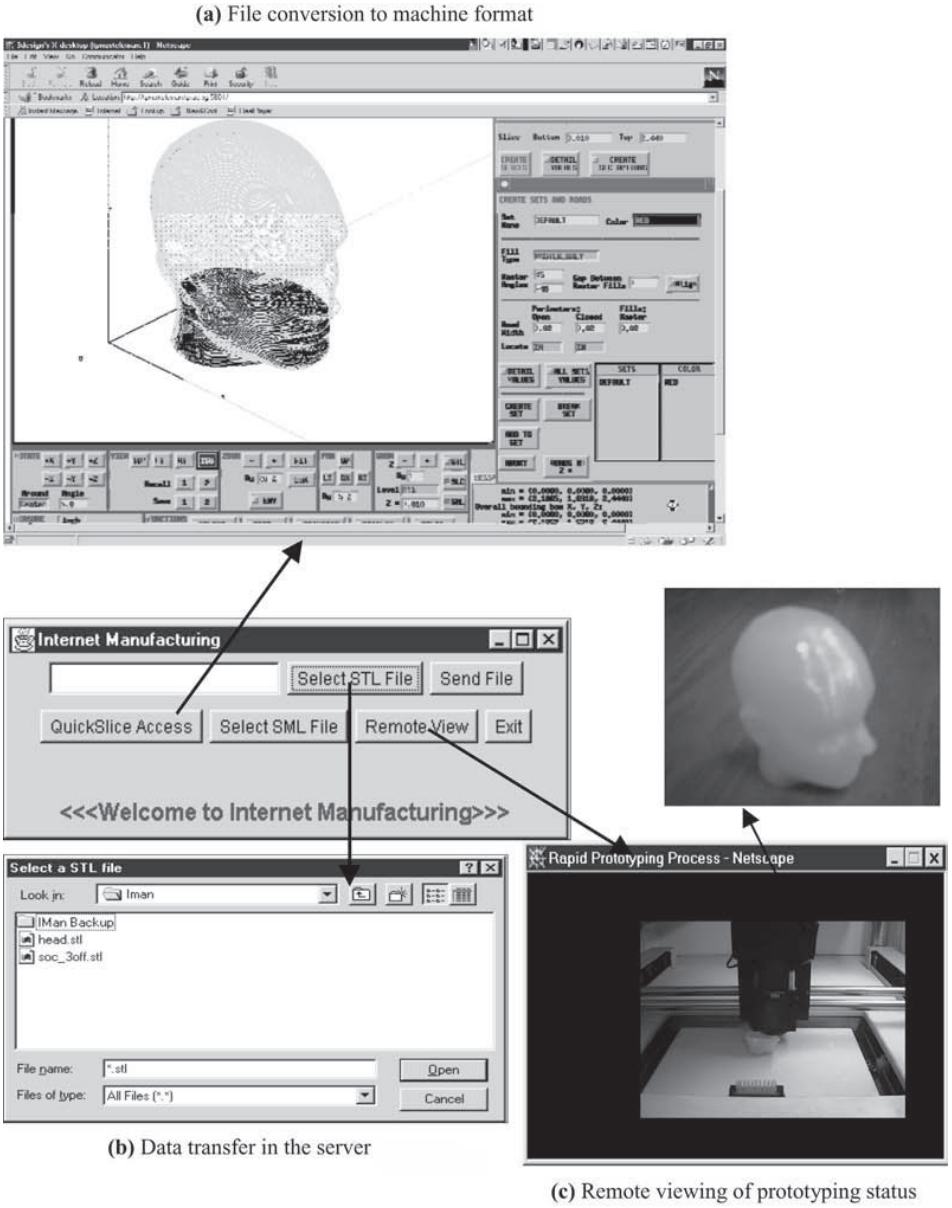


Tests and results

Tests were carried out in collaboration with Osaka University (Osaka, Japan). The main concerns were to validate reliable data transfer (see Figure 4) and successful access to the remotely located server applications for data conversion to machine format, remote fabrication of prototype and validation of the quality of the fabricated prototype. To validate the reliability of data transfer, network performance reliability was monitored in the rapid prototyping laboratory. Figure 4 shows the average distribution of network traffic in a week recorded in the rapid prototyping laboratory. The Internet connection from the laboratory to Osaka University is via the Asia and Pacific Advanced Network (APAN) link with a nominal 2 Megabit per second bandwidth. The network route is as shown in Figure 4. The multi-routed connection had heterogeneous transfer mode in each hub and obviously it was much slower in the international traffic from Singapore to the hub 203.181.248.217 (Osaka, Japan). Despite the heterogeneous data transfer, the quality of the fabricated prototype was very consistent. This implies that the data integrity is not dependent upon the heterogeneous data transfer mode.

The main factor of the validation is the fact that the converted CAD data should maintain its integrity to avoid any flaws over the long distance transmission so that its conversion to the machine format by the QuickSlice translator is not misinterpreted to form a bad prototype. It is shown that the quality of the prototype fabricated using the IMAN system is not susceptible to varying conditions of the network link, especially the data transfer mode.

Figure 3
(a) File conversion to machine format (b) Data transfer in the server (c) Remote viewing of prototyping status

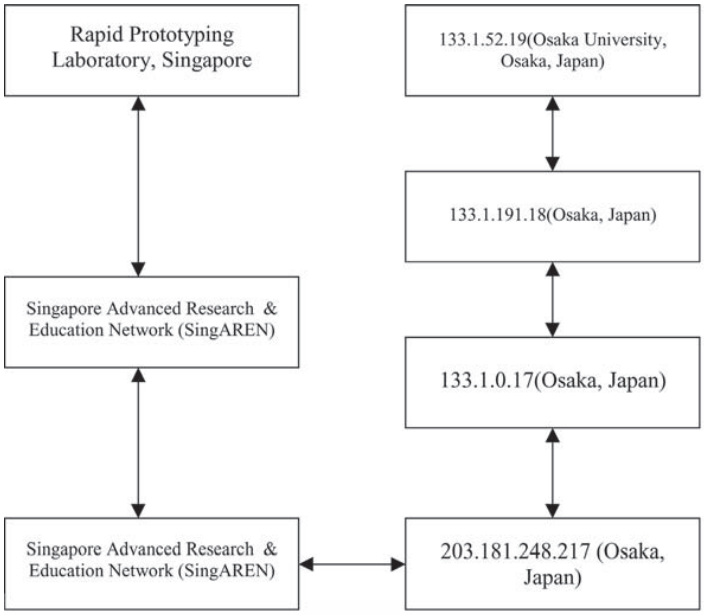


Conclusion

Distributed rapid prototyping using the Internet is a powerful tool in the product development process and scientific visualization field to enable the distributed resources to communicate in real time both virtually and physically. In this project, IMAN, which is based on modular software architecture, was developed to enable distributed rapid prototyping via the Internet. The approach is targeted at a wide range of audiences with disparate research and commercial interests in using rapid prototyping technologies remotely via the Internet. In particular, platform independency was a critical factor to ensure that end users using different computer systems can interact with the rapid prototyping center effectively. The modular

software architecture for the IMAN system is also highly scalable for further research and development. With IMAN, it becomes possible to collaborate in real time between two geographically distributed resources (partners). More effective utilization of geographically distributed resources is realized using one at the cheapest source of data carrier – the Internet as the means of communications. In the global manufacturing and design arena, industrial competition through successful product development based on efficient prototyping can be further enhanced by the use of the distributed rapid prototyping system via the Internet for remote prototyping to considerably reduce the product development lead time.

Figure 4
Network link and performance reliability



System:	ATM_Router in
Interface:	LEC.3.4 (10)
IP:	70001.tp.ac.sg (152.226.70.1)
Max Speed:	19.5 Mbytes/s

The statistics were last updated on Friday, 12 February 1999 at 15:47, at which time the ATM_Router had been up for 10 days, 1:12:19.

Monthly' Graph (2 Hour Average)

Max In:	3591.0 kb/s (2.3%)
Average In:	189.2 kb/s (0.1%)
Current In:	86.7 kb/s (0.1%)
Max Out:	2019.8 kb/s (1.3%)
Average Out:	41.2 kb/s (0.0%)
Current Out:	14.3 kb/s (0.0%)

Future research works

The proposed distributed rapid prototyping system is presently being developed for other prototyping hardware other than FDM. A highly interactive GUI will also be designed to communicate with the Programmable Logic Controller that will be connected to the front-end terminal to achieve more intelligent functions of the system remotely.

Current research work also involves the development of object-oriented collaborative CAD on the Internet. These two approaches will be merged in the near future to facilitate collaborative product development using the Internet.

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