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OBSERVATIONS FROM MULTIDISCIPLINARY, INTERNET-BASED COLLABORATION ON A PRACTICAL DESIGN PROJECT

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1 Introduction

Industry and academia are increasingly demonstrating the benefits of Internet based collaborative work for product design and development. For example, collaborating via the Internet for design teams at Boeing, and efforts to understand and support the design process at Stanford University, showed promising results [1, 2]. The US government's National Advanced Manufacturing Testbed (NAMT) project aims to set standards for future design and manufacturing practices by demonstrating the use of networked machines, software and people [*www.mel.nist.gov/namt*]. The NAMT project provided us a testbed to analyse and further explore usefulness of Internet-based collaborative design. In this case study, we have used two different Internet based approaches to support the design process. In our first approach, we have used a client-server based suite of tools to facilitate design activities and capture design rationale. In the second method we used VRML as a communication and visualisation medium for evaluation of detailed designs. We draw observations from both the experiments and analysed them in terms of their benefits for the design process and the end product. In this paper, we report our analysis results, and abstracting from these results, we present a set of requirements to further Internet-based collaborative tools.

2 The Design of The Artefact Transport System

As part of the NAMT, an Artefact Transport System (ATS) is being designed to transport *atom-based* Silicon artefacts from their manufacturing laboratory—the Molecular Beam Epitaxy (MBE), to their measurement laboratory—the Scanning Tunneling Microscopy (STM) [*www.mel.nist.gov/namt/projects/nano*]. The atom-based artifacts have dimensional features at the order of a nanometer. These artefacts need to be preserved in highly clean environment, a Ultra High Vacuum (UHV) at the order of 10^{-10} torr ($< 10^{-7}$ Pa), to protect their dimensional features. Therefore, the ATS should not only be compatible with existing MBE and STM machines, in order to withdraw and deposit the artefacts, and also maintain the high vacuum conditions throughout the transfer.

The design team for developing ATS consisted of specialists from different laboratories including the individuals who eventually use the ATS for measurement studies on the artefacts. The collaboration requirements of the team, and why we felt Internet based collaborative support for the team was desirable are discussed in the following section.

3 Requirements for ATS Design Process

To improve how designers work together, several researchers are studying the design process of teams. For example, Minneman [6] discusses social interaction among the designers in shaping the product, while Frankenberger et. al [3] describe engineering and psychological influences on the designers. While some authors analysed finer details of the design process, such as gestures [10] and communication media [1], others viewed it in broader terms in an attempt to support the designers [9]. An in-depth model of involving many factors, such as the ones depicted in Figure 1, is still required for a greater understanding of team design process. In the ATS design project, the ingredients shown in Figure 1 can be found. The design team consisted of physicists, mechanical, control and software engineers, with a 25-year spectrum of age and experience, each of whom used various software packages on a variety of hardware platforms during the design of ATS.

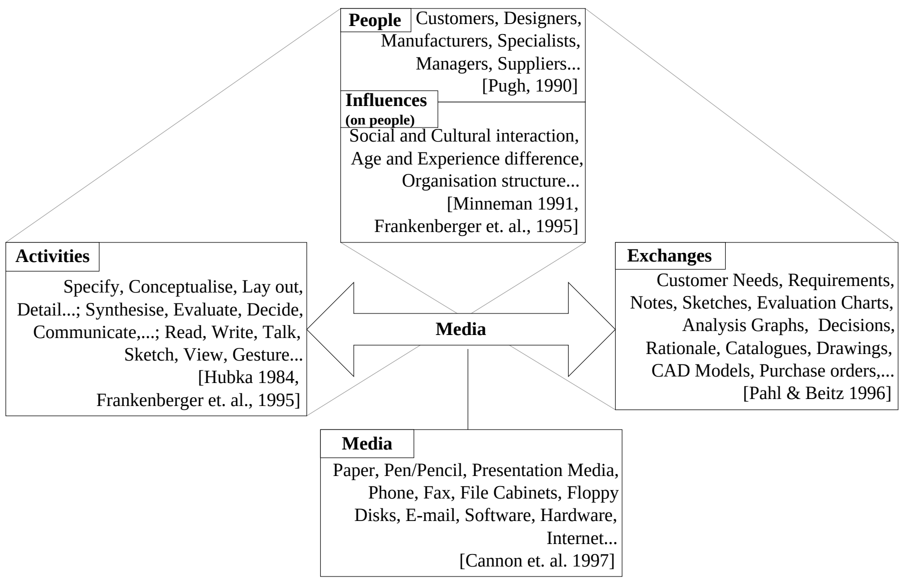


Figure 1: Ingredients of a team design process. A summary of several researchers' work highlighting people involved, their activities, information exchanges and collaboration media—team members collaborate through various activities and exchange information using a number of media.

The team consisted of 15 individuals in three core groups. Two of the groups are comprised of physicists who work on MBE and STM machines. The third group, with mechanical engineering experience (of more than 25 years per person), served as designers and fabricators of ATS. As customers, the physicists provided the mechanical engineers the needs of the ATS, and as experts they helped in conceptualising the initial solutions. As a result of this inter-dependence, common understanding among physicists and engineers was a critical link for the success of ATS design. Several face-to-face meetings among physicists and engineers took place for consensus approval of ATS functions, and later in the process, of the ATS detailed parts. Due to individual time constraints, however, not everyone from the core groups were able to attend all meetings. This affected the common understanding of the ATS.

In one late meeting, some physicists were surprised to see that their requirements for an extra vacuum valve, to further protect the clean-room environment, were not met. While the others were equally surprised as, according to them, the valve issue was discussed almost one year earlier, and decisions were taken against the valve (only a few members were aware of those decisions and arguments raised during the decision making). At the end of that chaotic meeting, the project leader reasoned for the misunderstanding that he was unable to get everyone to the meeting place at the same time to discuss design issues.

We realised that the designers' process can be improved

- if the common understanding is improved by encouraging all the members to share the design information irrespective of their attendance to face-to-face meetings, and
- the design rationale, such as evaluation arguments and decisions, is recorded and made available for future purposes such as referring to the past decisions or re-using for the next version of ATS.

We saw the opportunity that both the above aims can be met if we encourage designers to collaborate through computer supported platforms that allow all the members participate in the design process from their own office and on their own available time. We chose Internet as a medium of collaboration as it was readily available for all the members. We have used two approaches to improve collaboration among the designers. The following sections describe these two approaches and discuss results of their implementation.

4 Collaborative Design Using Internet Workbench

We have used ipTeam, a suite of software tools developed by NexPrise, Inc. [*www.nexprise.com*], to provide a collaborative platform for the team members. The ipTeam is a secure client-server suite of tools based on Internet protocol. The users of the tool can access the server area by password protected entry (controlled by HTTP server security and SSL encryption), create a project area on the server, and choose appropriate members as for the collaboration team. All information related to a project resides on the server. The project area provides three major services—an Internet Notebook, a Project Document Vault, and a Message Center—to co-ordinate asynchronous collaboration.

While the Document Vault and the Message Center are interfaced through an Internet browser, clients such as Netscape or Microsoft Internet Explorer, the Internet Notebook is a client developed by NexPrise. The Document Vault is used to archive design documents (such as project definition documents and CAD models) in a series of folders with appropriate keyword for navigation. The members are allowed to upload, download, review or edit Document Vault's contents as per their access rights. The Message Center helped to create mailing lists for the project team to send or receive messages related to the project (such as drawing attention of the team to changed documents on the Document Vault). The use of these services presented little change for the members as they are already familiar with the Internet browsers and email facilities.

The Internet Notebook is a multimedia environment for collaborative authoring. It allows users to sketch, paste images, and annotate with text, graphics, audio or video. The Notebook can have several entries, each entry related to a design issue, and the entries can be inter linked as a way to record the design rationale. The Notebook entries can be shared asynchronously via the server, and a member can notify any changes to the entries using the Message Center. Figure 2.a shows a snapshot of annotated discussion of ATS internal mechanism between two team members using a Notebook entry. The Notebook and the Document vault, along with the Message Center, have been successfully exploited by the team in solving several design problems for the ATS. Some of the problems include resolving compatibility conflicts between ATS and MBE, design of a datalogger to monitor ATS' travel, ATS-cart assembly, and control and operation of ATS.

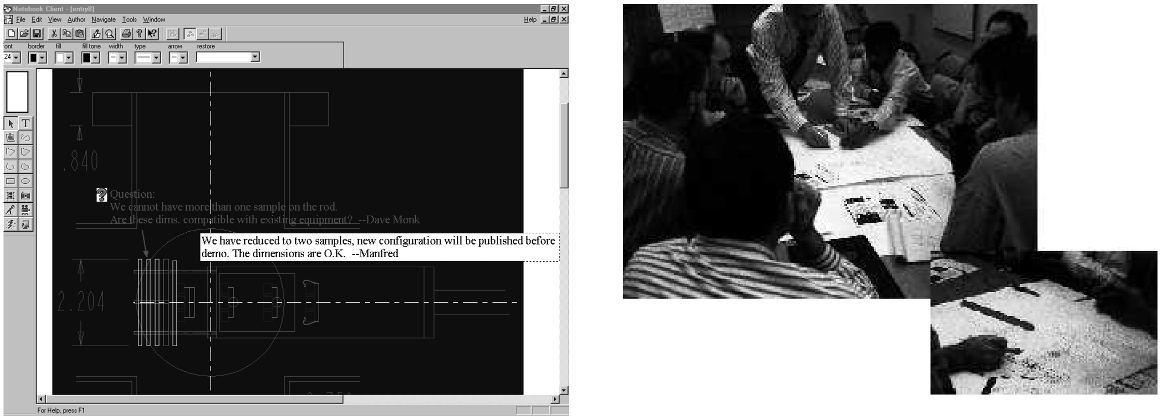


Figure 2: a) Collaborating through ipTeam's Internet Notebook, b) Natural face-to-face collaboration (inset showing close-up of a gesture).

The internal mechanism of ATS was conceptualised in a joint face-to-face meeting between STM physicists and mechanical engineers. The MBE physicists were not consulted due to their unavailability at this stage. After the design has been published on the Notebook, MBE physicists viewed and evaluated the design on their own time. They then informed the mechanical engineers of certain conflicts with the MBE requirements by republishing the same entry with their comments. These comments were helpful to the mechanical engineers in resolving the conflicts.

After some improvement in the design using the Notebook, a face-to-face meeting with all the members helped to completely resolve the issues—conflicts with both MBE and STM machines, conformance to the rest of the assembly, and economic factors. This meeting was felt necessary for all the members simultaneously needed to view and discuss the design. The ipTeam currently cannot facilitate simultaneous *visual* and *vocal* input from all the members at real time. Figure 2.b contrasts natural face-to-face meeting with that of a Notebook's text and graphics based collaboration, Figure 2.a.

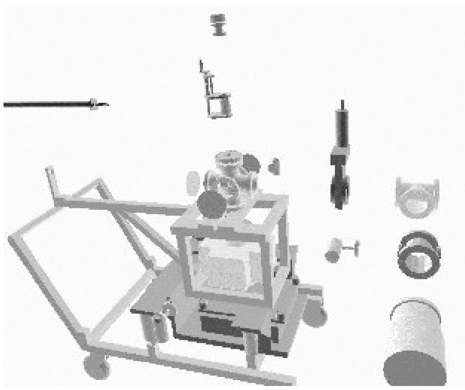
The ipTeam suite helped members identify, and have a common understanding of, the design problems before they were able to resolve them through the face-to-face meetings. The discussion using the Notebook also captured the arguments used by individuals, thereby creating a record of design rationale.

5 Evaluating the Design Using VRML based Visualisation

Our next approach to enhance collaboration was to present the assembly sequence and the assembled parts of the ATS to the team members so that each could visualise, evaluate, and comment on, details of the design. The CAD files of ATS were developed by using two packages—CADKEY [*www.cadkey.com*] and ProEngineer [*www.ptc.com*]. This presented us with three tasks, 1) integrating the ATS parts modelled in the CAD tools, 2) representing the assembly and its sequence animation and 3) presenting the assembly to the team.

We chose Virtual Reality Modeling Language (VRML[4]) as a medium because 1) it allowed to treat geometry files as in-line files (like linked documents in hypertext) to integrate various assembly parts, 2) it allowed animation of its geometry parts to develop the assembly sequence, 3) it can be presented on various hardware systems through VRML browsers like CosmoPlayer [*cosmo.sgi.com*] via the Internet, 4) VRML browsers facilitated VR functions, such as immersion and walk-through, to view detailed models for any number of views. Unlike the web-browsers in the previous experiment, the team members in this case are not familiar with VRML as a medium to communicate detailed designs. Therefore, we, as a support to the team, developed VRML representation of ATS and thereby tested its usability.

We found the CAD packages differed in their mechanism of exporting their geometry files to VRML. Therefore, we first re-implemented all CADKEY parts in ProEngineer, using an initial translation via IGES medium, and then translated ProE part files to VRML. We have used CosmoWorlds, on a Silicon Graphics (SGI) workstation, to edit VRML files to animate the assembly sequence. We then used our web-server to make the assembly available to all the team members. Figure 3 shows our effort to build, and a snapshot of, the assembly sequence animation of the ATS.



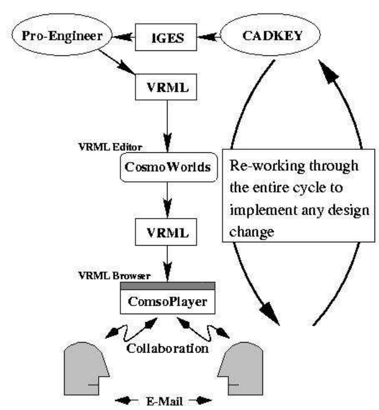


Figure 3: a) A snapshot of ATS assembly sequence animation, b) The effort to develop assembly sequence animation for the ATS.

All the members, who were using Windows95/NT and SGI, were able to visualise and analyse the static assembly of ATS. However, the assembly sequence, because of its file size, had to be animated only on SGI workstations. We, therefore, used a video-wall to project the assembly sequence for all the members to evaluate it. This exercise helped team members identify some spatial constraints and parts compatibility in the assembly.

VRML development effort was considerable and VRML depictions do not represent parametric information. Despite these drawbacks, VRML does provide a file format to integrate geometry data modelled in different CAD packages, can be used to successfully present solid models over the Internet. The VRML browser provided an excellent visualisation tool for team members to evaluate the design and assembly sequence.

6 Conclusions

The ipTeam facilitated collaborative design activities, such as sketching and evaluating, asynchronously, while capturing part of the design rationale. These tools supplemented ATS design team’s face-to-face meetings by improving time to reach consensus on design issues. As we have observed and elsewhere [2], the Internet tools did not support designers when a simultaneous input from all the individuals was required in real time. Solutions like video conferencing may provide a real time communication but they lack in supporting *visual* input, such as gestures (Figure 2.b), needed for collaboration. As Tang [10] points out, the designer uses gestures to direct the team's attention to the workspace (e.g. a sketch) or to another participant, and there by try to express ideas or mediate interaction. Participants using a video conferencing system can only gesture at his/her screen rather than the workspace or another person. This requirement needs to be addressed for a better collaborative tool.

Although VRML authoring effort was highly subjective to CAD packages and hardware systems (Figure 3.b), we found VRML representations very useful to integrate solid models from different sources, present animated objects, and visualise them over the Internet. While current hardware technology limits this activity to high-end machines, this is a short term problem. With CAD software implementing VRML export functions, one aspect of interoperability problem among CAD packages should be solved. However, these extensions currently do not address animation to model assembly simulation.

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