Rapidly Incorporating Real Objects for Evaluation of Engineering Designs in a Mixed Reality Environment

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Abstract

We explore using a Mixed Environment (ME) system to rapidly incorporate and visualize real objects into virtual environments (VEs). In this paper we discusses some preliminary results of a system to enable users to manipulate scanned, articulated virtual representations of real objects, such as tools, parts, and physical correlates to complex computer-aided design (CAD) models. Engineers and designers are capable of effectively conducting assembly design verification, as the ME can simulate these tasks at a high degree of fidelity. We have partnered with NASA Langley Research Center, and aim to use MEs to aid in creating assembly documents for upcoming payloads from CAD model designs.

Keywords: Virtual Environments, Interaction, Rapid Prototyping, Engineering Design.

1. Introduction

1.1. Historical context

Engineering design and evaluation has been a traditional application target for virtual environments (VEs). However, after years of research and development, successes are still limited, with few systems in actual use. This is due primarily to the difficulty in simulating engineering design and assembly verification tasks at a high degree of fidelity.

We aim to apply a *new type* of VEs. Instead of an *entirely virtual* environment, engineering design tasks need a Mixed Environment (ME), a combination of a few real objects with many virtual objects. Our ME system employs a pipeline to rapidly incorporate real objects and develops a means for multiple parties to view and interact with the proposed designs.

As tasks that rely on manipulating real objects, engineering design and assembly verification were the driving forces that guided development and evaluation of MEs. NASA Langley Research Center (LaRC) is a client for engineering design aides, and we partnered with LaRC to obtain content and end-user feedback.

In the integration stage, devices are connected with cables, parts, and tools. However, issues often arise when components come together for the first time. It is not unusual for payload subsystems to be developed both in-house at NASA, and by multiple subcontractors. Despite detailed planning and frequent reviews, subsystem layout issues are common. We look to develop a tool to effectively simulate integration in order to minimize these risks. This tool would allow for real-time modifications, provide haptic feedback with a "real-world" look and feel, allow for extemporaneous inclusion of tools and parts, and support multiple users with varying roles (Figure 1).
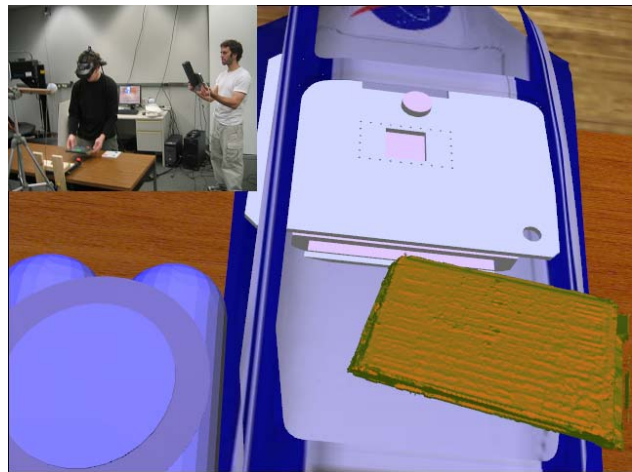

Figure 1 – First person and third person (*inset*) views of an assembly task being conducted in a mixed environment.

1.2. Approach

To extemporaneously incorporate real objects, we need to: Create virtual representations of the real objects involved in the assembly plan; Track the real objects such that the corresponding virtual representations mimic the real objects' motion and articulation; Insert the virtual representation in the ME, such that they are active participants in simulations.

To *rapidly capture the shape of the real object,* the object is first scanned with a Cyberware 3D laser scanner and imported into our environment after processing. *To track the real object*, simple colored markers are affixed to the object, then, the object is brought into the ME's working volume and tracked by outside-looking-in web

cameras with the STRAPS tracking library [1]. The primary user wears a head-mounted display (HMD) to visualize the 3D models in the ME. (S)He can pick up tools and parts and see the corresponding models move in the HMD. Other team members can also participate by viewing the ME using a *Magic Lens* (tracked Tablet PC) and via a LAN or the Internet.

For parts that the user needs to interact with, yet for which only CAD models exist (*e.g.* objects yet to be manufactured), the system presents physical correlates, such as a real cardboard box, to represent virtual models.

In this paper we discuss our preliminary experiences with using real tools and parts to explore and evaluate engineering design.

2. Previous work

The automobile industry is leading the charge in applying VE technology to the design process [2]. Typical installations allow the user to sit in a real car seat with access to a real steering wheel and a dash mock-up. A designer can interact with the virtual vehicle and receive natural feedback from the physical devices.

Levoy, et. al., captured 3-D models of sculptures with range data from laser scanner [3]. Raskar, et. al., generated 3-D models of participants from multiple camera images for distributed interpersonal communication [4]. Matusik, et al., have developed an image-based visual hull approach, which used image-based rendering algorithms to calculate real object approximations at interactive rates [5, 6].

Some VE systems provide tracked, instrumented real objects as input devices. Zachmann used tracked articulated gloves with gesture recognition and buttons, mice, and joysticks [7]. Hand and Bowman provide good summaries of studies of interaction in VEs [8, 9].

A few high performance solutions are available, such as 3rdTech's HiBall-3100[tm] and Intersense's IS-900[tm]. Inertial tracking systems are small and unobtrusive, but suffer from drift over time and must be recalibrated periodically with another type of tracking method. Magnetic tracking system sensors are small and easy to wear but range is limited and performance is adversely affected by ferromagnetism [1]. Further, most tracking systems report the position of relatively few sensors.

3. Virtual evaluation pipeline

3.1. Capturing object shape

Our goal is to capture complex real world objects, such as tools and parts used in engineering design. The objects are first scanned with a CyberWare 3D Laser Scanner (Figure 2a). Since these objects typically have complicated shapes, it impossible to capture the whole

surface in one scan. A common solution is to scan the object multiple times with different poses, and then merge the resulting scans into a single model. We follow a pipeline similar to "The Digital Michelangelo Project" [3] in processing the scanned data from the 3D scanner:

We developed a program to remove extra facets (noise or the support material for the scanned object) in the scanned data. Freeware libraries were used to align multiple scans and merge them into a single model (Scanalyze and Vrippack) [10]. Holes in the final model are filled using an algorithm based on [11].
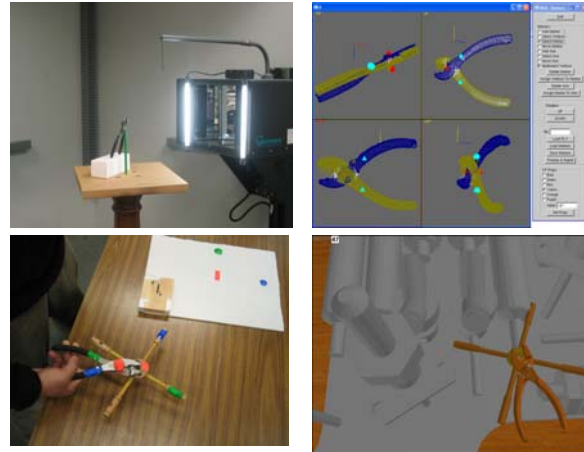

Figure 2.   *a.* Scan a pair of pliers
                b. Assign the marker positions
                c. Tracked pliers pickup an object
                d. Technician's view of the procedure

Degrees of freedom of the tool are defined, such as the axis of rotation in the pair of pliers in Figure 2b). Colored markers are attached to the physical object (Figure 2c). A GUI is used to identify the corresponding marker location on the scanned model.

3.2. Tracking the objects

We adapted a simple colored-marker tracking system, STRAPS [Jackson et. al. 2004]. It is particularly applicable to assembly design because it is untethered and scalable with moderate latency (~150 ms).

STRAPS is a camera-based multi-color tracking system. It uses web cams to search the scene for the color markers. The 2D image positions of the colored markers are transferred to a server where ray intersection is applied to compute a 3D position (center of gravity) of the colored marker.

The original library could track only six colors. However, with the number of objects we eventually aim to track (fifteen or more), we needed to extend the tracking capabilities.

We extended the original STRAPS system by enabling it to recognize multiple markers of the same color (multi-blob tracking). Instead of searching only for the largest

blob of each color, all blobs larger than a certain threshold are reported to the STRAPS server. Then temporal coherence, spatial coherence, and spatial relationships of markers on objects are used to disambiguate (or derive a best guess) multiple tracked blobs of a similar color. Reusing tracked colors increases the number of simultaneously tracked objects.

We used four IBot2 USB2.0 web cams. In the future, we are planning to build a tracking solution with more cameras to solve the problem of occlusion. We used Dell P4 3.0 Ghz PCs for STRAPS tracking. Each pair of cameras is connected to one PC to capture images and catch the markers, while another separate PC constructs the 3D positions.

3.3. Visualizing objects

Assembly verification is a team effort, with team members having varying tasks, objectives, talents, roles, and locations. This translates to various viewing requirements of the ME.

We provide three different visualization platforms to support team-based evaluation of engineering design.

1) HMD for primary user: The assembly technician needs to visualize and conduct the task in the ME similarly to the way he would in reality. This requires the hands-free first-person perspective provided by a head-mounted display (HMD). Our ME system uses a Virtual Research V8 from EBY Systems (640 x 480 resolution, 60 Hz, stereo). The position and orientation of the user's head are tracked by a commercial tracking solution (WorldViz PPT tracker and an Intersense InertiaCube2).

Figure 3. Secondary local users use a *Magic Lens* to view the virtual assembly procedure in the ME.

2) Magic lens for local team members: Secondary local users (*e.g.* engineering and design team) carry a tracked Tablet PC (*Magic Lens*) – as a local window to view the assembly task in the ME. The Magic Lens is tracked by a second WorldViz PPT sensor and a Intersense InertiaCube2. The scene of the ME is rendered on the Tablet PC's screen accordingly (Figure 3). The Magic Lens allows for team members to naturally view the combination of real and virtual objects of the ME, while still allowing team dynamics, such as discussion and observing the 'bigger picture'.

3) Networked desktop for remote members: Remote users (*e.g.* subcontractors and distributed team members) can watch the ME on a desktop connected via a LAN or the Internet. The scene can be rendered from the viewpoint of the HMD, the Magic Lens, or a mouse-controlled 3rd-person perspective.

4. Conduct an abstracted task in the ME

To perform an initial evaluation of the applicability of the ME system to engineering design tasks, we conducted experiments with an abstracted layout task, using actual NASA payload models, parts and tools.

We first obtained CAD models for the ARES project, a proposed design for an airplane that would fly in the Martian atmosphere to obtain geological and topologic information. We also obtained real parts and connectors used in previous payloads. These included a circuit board and docking bay for the board. We rendered the ARES virtual models in the ME.

In an abstracted layout task, the user had to position a fuel tank and a circuit board inside the fuselage of the prototype ARES airplane. First, the assembly design called for the user to mount the fuel tank. The user had to rotate the fuel tank and then lower it inside the fuselage in order for it to fit. Next, the assembly design called for the user to insert the circuit board into a slot inside the fuselage. However, the fuel tank blocked the slot, preventing the user from inserting the board. The user realized the design flaw and adjusted accordingly.
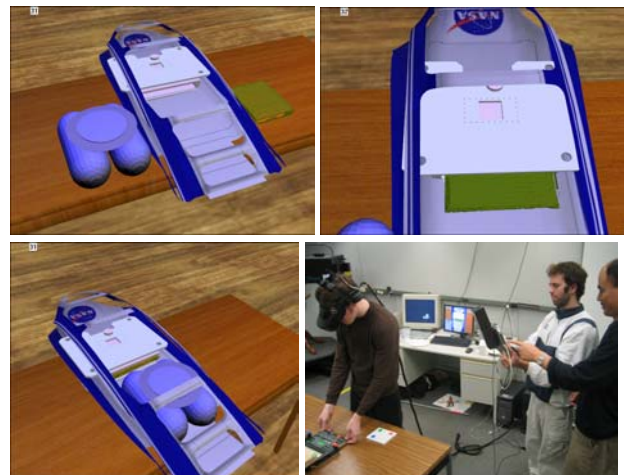

Figure 4. Conducting the virtual assembly procedure in the ME.

We conducted an informal trial of the layout task. Several participants, unfamiliar with the system, performed the task. All users detected the assembly error (which was relatively straightforward), and subsequently removed the fuel tank, inserted the board, and finally remounted the fuel tank (Figure 4).

Of note, the users interacted with both real and virtual objects, and conducted the evaluation, similarly as they would in reality. They maneuvered a real circuit board used in a NASA payload. We obtained the 3D circuit board model using our scanning pipeline. The user inserted the circuit board into a physical slot, which was represented in virtual by CAD models of the slot and the surrounding payload subcomponent. The virtual fuel tank was a CAD model from ARES design. Instead of lifting an actual fuel tank, the user handled a physical correlate, a small white box with attached color markers (*Figure 3a*). The model of the fuselage was a NASA CAD model as well but, because it did not need to be handled, we did not use a physical correlate.

5. Conclusion and future work

We have discussed our initial experiences with a pipeline to rapidly incorporate real objects into a VE. This enabled the user to handle real tools and parts while interacting with virtual objects. The preliminary results suggest that MEs could be applied to engineering design and assembly verification.

Further development will focus in four major areas:

• *Improving the accuracy and robustness of the colored marker tracking*: occasionally STRAPS loses track of one or more markers on an object, causing the correspondence between the real and virtual objects to be disrupted. The system needs to gracefully recover from the inevitable tracking occlusions.

• *Increasing the tracked volume and number of cameras*: We aim to expand to a ten camera ME system. This should reduce the impact of occlusions (a shotgun approach to tracking).

• *Provide an articulated user avatar*: this will improve the primary user's sense of presence, thus improving his efficiency and accuracy during verification tasks.

• *Formal evaluation of the system*: we will implement the system at NASA LaRC and conduct a formal study. Technicians will conduct the proposed ARES designs in the ME.

NASA LaRC plans to incorporate MEs into its existing "sim-to-flight" development environment. Scientists and engineers will be able to conceptualize a payload, fast-track its design and, with the addition of MEs, simulate its integration and test without any fabrication, not even a mock-up. Specifically, the development of Mars Airplane [http://marsairplane.larc.nasa.gov/] is a target application for MEs. ARES will launch in September 2007, reach Mars in September 2008 and complete its mission on the day of arrival. Mars Airplane (called ARES) is an autonomous, powered vehicle for gathering simultaneous, in-situ, regional-scale measurement of the Mars atmosphere, surface, and interior. Its integration is especially challenging due to its size and complexity.

References:

[1] JACKSON, J., LOK, B., KIM, J. XIAO, D., HODGES, L., SHIN, M. "Straps: A Simple Method for Placing Dynamic Avatars in a Immersive Virtual Environment." Future Computing Lab Tech Report FCL-01-2004. Department of Computer Science, University of North Carolina at Charlotte. 2004.

[2] BROOKS, F. 1999. What's Real About Virtual Reality? In IEEE Computer Graphics and Applications. Vol. 19, 6, 16-27.

[3] LEVOY, M., PULLI, K., CURLESS, B., RUSINKIEWICZ, S., KOLLER, D., PEREIRA, L., GINZTON, M., ANDERSON, S., DAVIS, J., GINSBERG, J., SHADE, J., AND FAULK, D. "The Digital Michelangelo Project: 3-D Scanning of Large Statues", In Proceedings of ACM SIGGRAPH 2000, pp. 131-144, 2000 [9]

[4] RASKAR, R., WELCH, G., CUTTS, M., LAKE, A., STESIN, A., AND FUCHS, H. "The Office of the Future: A Unified Approach to Image-Based Modelling and Spatially Immersive Displays", Computer Graphics. M. F. Cohen. Orlando, FL, USA (July 19 - 24), ACM Press, Addison-Wesley: pp. 179-188.

[5] MATUSIK, W., BUEHLER, C., RASKAR, R., GORTLER S., AND McMILLAN, L. 2000. Image-Based Visual Hulls. In Proceedings of ACM SIGGRAPH 2000, Annual Conference Series, 369-374.

[6] MATUSIK, W., BUEHLER, C., AND McMILLAN, L. "Polyhedral Visual Hulls for Real-Time Rendering", In Proceedings of Twelfth Eurographics Workshop on Rendering, London, England, June 2001, pp. 115-125.

[7] ZACHMANN, G. AND RETTIG. A. "Natural and Robust Interaction in Virtual Assembly Simulation", Eighth ISPE International Conference on Concurrent Engineering: Research and Applications (ISPE/CE2001), July 2001, West Coast Anaheim Hotel, California, USA.

[8] HAND, C. 1997. A Survey of 3-D Interaction Techniques. Computer Graphics Forum, Blackwell Publishers, Vol. 16, 5, 269-281.

[9] BOWMAN, D., AND HODGES, L. 1997. An Evaluation of Techniques for Grabbing and Manipulating Remote Objects in Immersive Virtual Environments. In Proceedings 1997 ACM Symposium on Interactive 3-D Graphics, 35-38.

[10] CURLESS, B., LEVOY, M., A Volumetric Method for Building Complex Models from Range Images. In Proceedings of ACM SIGGRAPH 1996. 303-312.

[11] LIEPA, P. 2003. Filling holes in meshes. In Proceedings of the Euro-graphics/ACM SIGGRAPH symposium on Geometry processing, Eurographics Association, 200–205.

[12] Lok, Benjamin, Samir Naik, Mary Whitton, and Frederick Brooks (2004). "Experiences in Extemporaneous Incorporation of Real Objects in Immersive Virtual Environments," In Beyond Glove and Wand Based Interaction Workshop, IEEE Virtual Reality 2004, Chicago, IL.