A Pipeline for Rapidly Incorporating Real Objects into a Mixed Environment

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Abstract

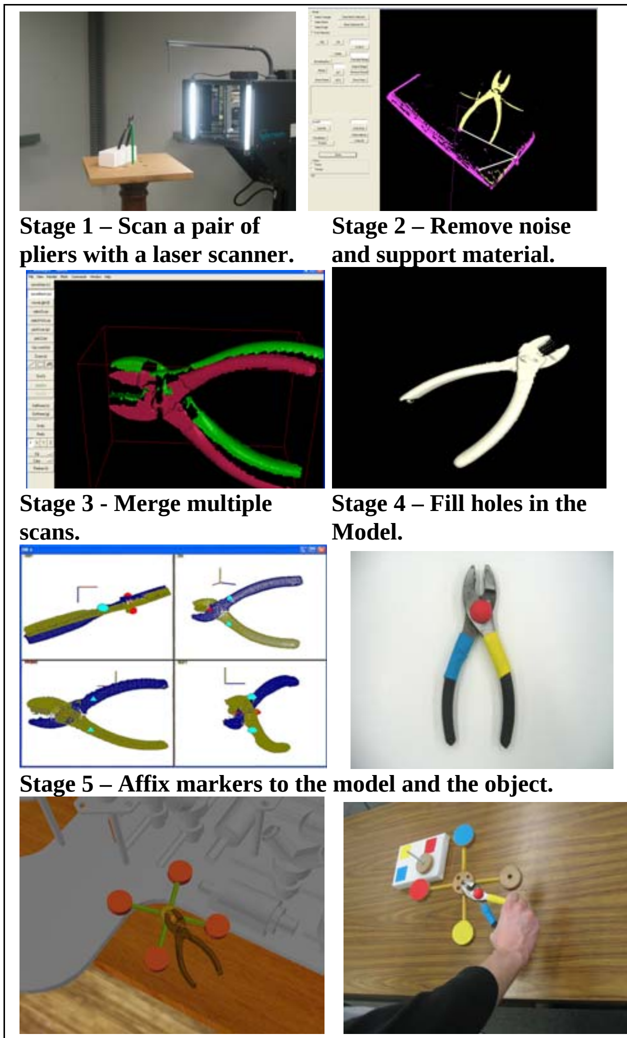
A method is presented to rapidly incorporate real objects into virtual environments using laser scanned 3D models with color-based marker tracking. Both the real objects and their geometric models are put into a Mixed Environment (ME). In the ME, users can manipulate the scanned, articulated real objects, such as tools, parts, and physical correlates to complex computer-aided design (CAD) models. Our aim is to allow engineering teams to effectively conduct hands-on assembly design verification. This task would be simulated at a high degree of fidelity, and would benefit from the natural interaction afforded by a ME with many specific real objects.

1. Introduction

Incorporating real objects into Mixed Environment (ME) systems is a non-trivial task, and if the goal is to incorporate a *specific* real object, it could become logistically difficult (if not impossible) and time consuming. However, real objects provide the core benefits of MEs, haptic feedback, natural interaction and better affordance.

We present a pipeline for the rapid incorporation of real objects into mixed environments (Figure 1). Our approach is a combination of laser scanning and color-based marker tracking to provide an immersive experience such that the user can interact with several real objects among many virtual objects. First, a Cyberware 3D scanner is used to generate a virtual model of the real object with several scans (Stage 1). Next, the user removes noise and support material (Stage 2), aligns multiple scans (Stage 3), and fills in holes from the scans (Stage 4).

To track the real object, simple colored markers are affixed to the object (Stage 5). The user uses a GUI to identify the corresponding marker locations (and degrees of freedom) on the 3D model. Using the STRAPS tracking library [1], the colored markers are tracked from multiple live web-camera streams. The tracked positions



Stage 1 – Scan a pair of pliers with a laser scanner.
Stage 2 – Remove noise and support material.
Stage 3 - Merge multiple scans.
Stage 4 – Fill holes in the Model.
Stage 5 – Affix markers to the model and the object.
Stage 6 – Interact with pliers inside the ME.

Figure 1- Stages of the Pipeline.

of the markers are used to determine articulation, and render the scanned models accurately in the ME (Stage 6).

The resulting pipeline allows for real objects to populate a mixed environment in less than two hours. Further, improvements in any stage can be 'plugged' into the pipeline to improve overall performance or quality.

We aim to apply MEs to engineering design verification, specifically NASA payload assembly. For the assembly task to be simulated at an adequate level of fidelity, *real tools and parts are a requirement*. As engineering design review is our system's driving application, our pipeline approach is called: Mixed Environments for Review and Generation of Engineering Designs (MERGED).

2. Previous Work

2.1 Creating Geometric Models for VE

To incorporate real objects into a VE, the shape and surface appearance of the real objects must be captured. For articulated objects, the relative motion must also be modeled.

Precisely measured objects are required to create accurate 3D models in a modeling package. This is laborious for complex static objects, and nearly impossible for capturing all the degrees of freedom of complex dynamic objects. With multiple real objects in a scene, obtaining models for a ME is a non-trivial task.

[4] captures 3-D models of sculptures with laser scanning for education, visualization, archiving, and exploration. Raskar generates 3-D models of participants from multiple camera images for distributed interpersonal communication [6].

Similar in spirit to this work are Augmented Reality (AR) systems [3], which incorporate a few virtual objects with the real world. Our work focuses on incorporating a few real objects with a VE. We decided against using AR in our system because it depends too much on fixed camera viewing, which would not allow remote users unique view points.

2.2 VE Interaction

Similar to our approach to manipulating virtual objects through real correlates, [7] reported on the performance of controlling virtual objects in VE through handling a real representative object. They showed that putting their hand into the working volume is important to improve interaction performance. Further, correlation between the shape of the virtual and real objects did not improve the interaction performance.

2.3 Tracking of Objects in VEs

Systems for tracking and motion capturing for interactive computer graphics have been explored for over 30 years [8]. Where significant infrastructure is possible, researchers and engineers have succeeded in developing relatively high-performance systems such as 3rdTech's HiBall-3100™ and Intersense's IS-900 ™. However, a high level of performance remains the goal whether significant infrastructure can be supported or not.

Previous results on the quality and impact of the interaction provided by our ME for engineering design has been reported in [9]. This paper will focus in more detail on the pipeline of MERGED system.

3. MERGED Pipeline

The goal of the MERGED system is to allow users to be immersed within a virtual world, using a Head Mounted Display (HMD), while manipulating real objects. The user will see the results of their interaction in real-time to virtual models that are mapped to the real objects. The goal of the system is to enable technicians and engineers to effectively conduct and verify assembly and payload design tasks.

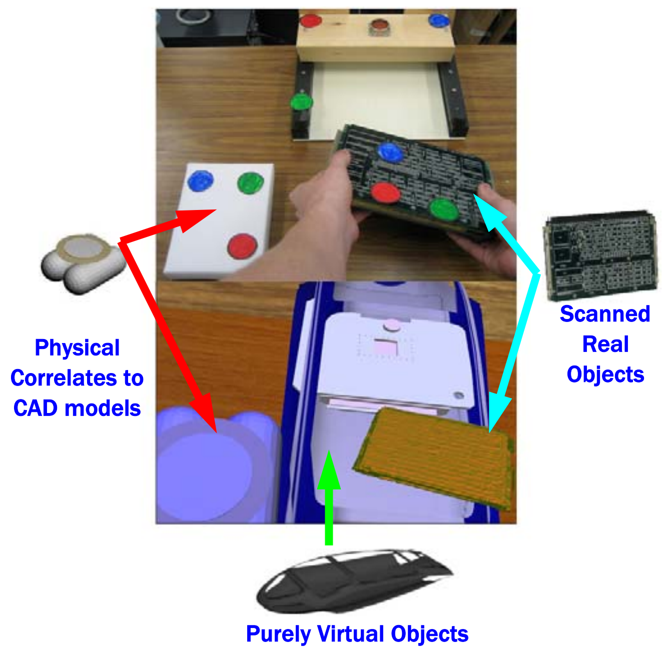


Figure 2 – There are three types of objects in our ME

There are three types of objects in our ME (Figure 2):

1. Purely virtual objects – these object exist only in the virtual world and are not central to the assembly verification. Examples would include the assembly hanger bay, and other subcomponents not critical to the task being evaluated
2. Virtual objects yet to be constructed – these objects are proposed designs that require validation. The user handles a representative

real object (physical correlate) which is affixed with color markers.
3. Real tools and parts – these objects have been created, and CAD models might or might not exist (ex. in a database). These objects are passed through the MERGED pipeline, and are rendered in the ME with their pose controlled by the tracked markers on the real object.

In the following sections we will introduce each stage of the pipeline:

1. Capturing real object shape.
2. Tracking real objects in the scene.
3. Interaction of the system.

4. Capturing Object Shape

To accurately verify assembly tasks, we need high fidelity virtual models of the real objects. In our system, we use a Cyberware 3D Laser scanner for capturing object shape.

MERGED uses a similar pipeline proposed in [4] to process the captured range data from the 3D scanner. However, laser scanning objects in engineering design (such as tools and parts) is not a straightforward procedure. Issues include:

- Objects could be relatively small (with respect to the scanning volume), and very greatly in size in different dimensions. For example, one dimension of a pair of pliers is quite thin, resulting in increased error in scanning and merging.
- Objects could be rigid (*e.g.* circuit boards), non-rigid with a few degrees-of-freedom (*e.g.* pliers, tools), or completely flexible (*e.g.* cables).
- Objects could have surfaces (*e.g.* metal or shiny surfaces) which can not be accurately reconstructed with a laser scanner.

Our Cyberware 3D Laser scanner scans an object by rotating the scan head 360 degrees about the object. It is not possible to reconstruct a model from a single scan due to occlusion and noise.

An object goes through the following pipeline steps to obtain a complete model:

- The object is scanned multiple times to capture range data from different positions.
- Range data is processed to remove extra data (*e.g.* supporting material) and noise.
- The scans are aligned with respect to each other as to properly merge the surfaces. To align, we use Scanalyze [5] which requires an initial alignment by hand, before performing the Iterated Closest Point algorithm.
- Multiple scans are merged into a single surface, using Vrip [2], removing overlapping parts.
- The holes in the resulting surface are filled to create a closed surface.
- The resulting model is simplified as the original scans contain more vertices then required.

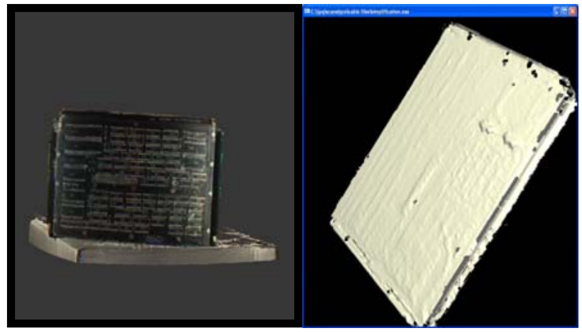


Figure 3 – Results from a single scan for the circuit board and the model before hole filling.

5. Tracking Objects

The real objects that the user is manipulating are tracked in order to appropriately transform the virtual objects in real time. To track the real object, colored markers are affixed to the object and their positions measured. The user uses a GUI to place markers on the scanned model (Figure 1 stage 5). For objects with articulation, such as a pair of pliers, the GUI allows the user to identify the degrees-of-freedom.

For tracking objects the user manipulates, we use STRAPS [1], a color-marker based tracking system. STRAPS is an inexpensive, untethered, scalable optical tracking solution with moderate latency (~150 ms).

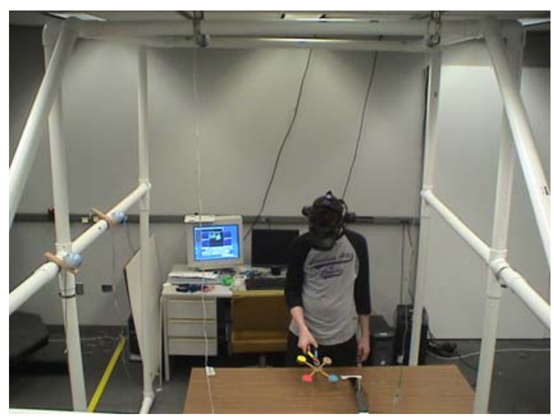


Figure 5 - PVC cage that houses 4 web cameras.

We have fabricated a PVC cage (Figure 5) that houses multiple outside-looking-in web cameras that are used as inputs to the STRAPS tracking library. STRAPS provides sufficient speed and resolution for our application and it is low cost and scalable.

STRAPS was extended to handle multiple instances of a tracked color (multi-blob tracking). Some spatial and temporal heuristics are used to correlate the reported color marker positions from the different cameras. Thus, by reusing tracked colors, unique colors are not required per tracked object. This allows us to have many simultaneously tracked objects in the ME.

We examined the performance of the object tracking. The testing methodology was similar to that in the original STRAPS report [1], but in a much smaller tracking volume. Our measured dynamic jitter is roughly about 0.002 (2 mm). And the end-to-end latency for the tracking system is 184ms. This value is almost double the result of [1]. We attribute this to the increased processing for the multi-blob tracking and the slightly lower frame-rate of the web cameras.

6. Experiment with a simple task

To demonstrate the potential applications of our system, we conducted an initial trial to evaluate the MERGED system with actual tools and parts used in engineering tasks [9]. This was not a formal evaluation of the system, but a first exploration incorporating and using production tools and models.

During the experiment, the users successfully incorporated and tracked all the objects. Moreover, they were able to complete the assembly tasks inside the ME with minimal instruction.

7. Conclusion and Future Work

We proposed a pipeline to rapidly incorporate real objects into a ME (MERGED). First the user scans the object from multiple angles and then removes any noise or support material using a GUI. Next the user merges the multiple scans and fills any holes. Then, the user affixes color markers to the real object and the model. Finally, the user can visualize and interact with the object in the ME. For most objects, a user can capture the shape of an object and track it inside the ME in 2 hours. We feel that this system is particularly applicable to engineering design.

The MERGED system is a prototype, leaving room for much improvement. Our future development will focus in several areas:

- *Improving the colored marker tracking for handling multiple objects* – the simple approach to tracking appears to work well. However, as the number of parts and tools to be tracked increases, a more rigorous tracking solution will be required. This includes using known inter-marker offsets, spatial coherence, and temporal coherence to handle the occlusions and additional objects.
- *Increasing the tracked volume and number of cameras* – using commercial, off-the-shelf components allows for easy scalability. We aim to increase the number of cameras to ten, and create a larger volume that is surrounded by input devices.
- *Formal evaluation of the MERGED* – with the system capable of an abstracted task, we are planning to conduct a formal study with payload design experts to learn how the MERGED would perform in evaluating actual designs. Also, we are planning studies to quantify the task performance and cognition advantages by comparing MERGED with completely virtual environments.
- *Automating parts of the pipeline* – We hope to reduce an object's incorporation time to 15 minutes.

8. References

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