Augmented Reality In-Situ 3D Sketching of Physical Objects

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ABSTRACT
We describe a multimodal 3D Sketching environment based on Video See-through Augmented Reality, allowing the freehand sketching of manufacturable 3D objects *in situ* with real-time visual feedback. Using a head-mounted stereo display (HMD), an optical tracking system, and head mounted cameras, we dynamically overlay 3D sketch strokes obtained with a wand onto the HMD in real time. This integration allows users to see the real world as they are drawing, enabling the use of physical world references in the creation of 3D content. The user then is able to accomplish tasks such as drawing a basket with suitable dimensions that will hold specific real world items, drawing a part that can be attached to an existing object, or even drawing a path that follows the movements of a moving object.

Author Keywords
3D sketching, motion capture, head tracking, augmented reality, computer vision, multimodal.

ACM Classification Keywords
H5.m. Information interfaces and presentation: Miscellaneous.

INTRODUCTION
An interface for the creation of digital 3D maps 2D or 3D input to 3D geometry. Three classes of such interfaces have been identified: Material, Mark Interpretation, and Thinking Through Structure [10]. In this paper, we are interested in Mark Interpretation, which is an interface that maps 2D or 3D continuous paths to 3D geometry. Within Mark Interpretation, interfaces either receive 2D or 3D input. Those receiving 2D input employ techniques to transform 2D input to 3D geometry such as interpreting a 3D cube from a paper sketch of a cube [12]. There have been a number of recent advances in this area such as the development of the Teddy system [7] and the SKETCH system [8]. Although this approach leverages the ease and precision of drawing in 2D, the difficulty lies in resolving the ambiguity in mapping two-dimensional information to three dimensions. Current systems can only approximate basic intended 3D shapes. The alternative approach, which is the approach taken in this paper, is to receive 3D continuous paths that directly correspond to 3D freeform lines. A tracking system tracks the position of a drawing apparatus operated by the user. By using sampled position points as points on a freeform line, the 3D sketch can be recorded and displayed in real time without ambiguity. Various systems have used this approach such as the Holosketch system [1] which uses ultrasonic trackers in a virtual reality environment, the FreeForm system which provides haptic feedback by providing resistance on the drawing apparatus when it comes into contact with virtual objects [9], and the Drawing Surface [10] which uses electromagnetic trackers in a virtual reality environment. We employ a Video See-through Augmented Reality interface similar to Holosketch and Drawing Surface but additionally enable the user to use the real world as a reference when drawing. For an Augmented Reality system, we must not only track the drawing wand, but also the pose of the user's head so that the perspective of the camera in the virtual world can match the user's perspective (i.e. the perspective of the head-mounted cameras). This way, when we overlay the sketch on top of the live video streams from the cameras, it will appear as if the sketch is in the real world.

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FREE-FORM SKETCHING IN 3D
The most popular interface for 3D content creation includes a display device such as an LCD or CRT monitor and an input device such as a mouse, tablet, and/or keyboard. The majority of 3D content generation applications are modelers that enable a digital creation process analogous to that of clay modeling. Drawing applications in which the user draws using a mouse or drawing tablet only permit drawing in a two dimensional plane in a single stroke. In order to achieve a desired 3D line, the user must perform operations such as changing camera perspective and adjusting splines.

An augmented reality based interface such as ours provides two distinct advantages over the prevailing interface: drawing 3D freeform lines is more natural and a live 3D reference can be used while drawing. For most people, sketching on paper is the most natural and accurate freeform 2D content creation process. With an augmented reality based interface, we can extend the freeform creation process to 3D. Drawing becomes as natural as moving a wand through 3D space. Whereas the modeling creation process provides high precision, it comes at the cost of performing more operations than free-form creation; 3D freeform sketching can enable quicker content creation. It must be noted that the transition from freeform sketching in 2D to 3D does incur some difficulties. People rest their hand on the table when drawing on paper, which both reduces fatigue and provides hand stability. Since this generally does not happen when drawing in 3D, the user may both experience arm fatigue quicker and lack the same hand control available in 2D. Additionally, any errors in tracking further reduce control. However, the reduced control in 3D can actually be a feature. For the Drawing Surface system, subtle shakiness in the user's hand produced a rough, organic surface that enhanced the realism of flowers and leaves created by the user. In cases where roughness is not desired, a smoothing operation could be applied to the drawing.

TRACKING SYSTEM

The tracking system consists of up to six infrared cameras mounted in a circle on the ceiling. We used commercial motion tracking cameras from Optitrack [11] for their reliable performance and readily available software libraries. We relied on built in tracking algorithms since these are not the focus of this paper. Another advantage of utilizing a commercial tracking system is the reduction of processing load. The tracking cameras handle all image processing tasks onboard individual cameras. This greatly reduces the load on the computer running the rest of the sketching program. It also allows us to easily add more cameras to increase tracking accuracy. We tested the accuracy of the tracking system by tracking two markers spaced 30cm apart on a ruler and compared the distance between the tracked markers to the actual distance between the markers. Within ~1m of the tracking origin (a point on the table near the center of the cameras), the error ranged from 1-3mm which is < 1% error. Position and orientation of tracked rigid bodies are sampled ~120 times per second. More accurate and faster tracking systems are available and would likely improve the performance of the system.

Improving Tracking Performance

We measure tracking performance in terms of two characteristics: stability and accuracy. Stability is the ability of the tracking system to not only identify rigid bodies across varying positions and poses but to maintain a smoothly changing identification of rigid bodies tantamount to actual changes in position and pose [5]. Reflective markers are placed on the drawing wand and HMD so they can be tracked by the infrared cameras. We define these sets of reflective markers as rigid bodies in the Optitrack software. Based on the relative positions of the markers, Optitrack can differentiate between the different rigid bodies being tracked and return the position and orientation of each rigid body. To increase tracking accuracy of these rigid bodies we experimented with the number, placement, spacing and shapes of markers. We found that defining a set of markers in an asymmetrical configuration reduces orientation ambiguity. We also found that there exists a tradeoff between tracking stability and accuracy when adjusting marker size [6]. Smaller marker size causes less jittering of the rigid bodies since the centers of the markers are better defined. However, smaller markers require fine tuning the camera exposure and threshold levels since smaller reflective surfaces have weaker signal strength.

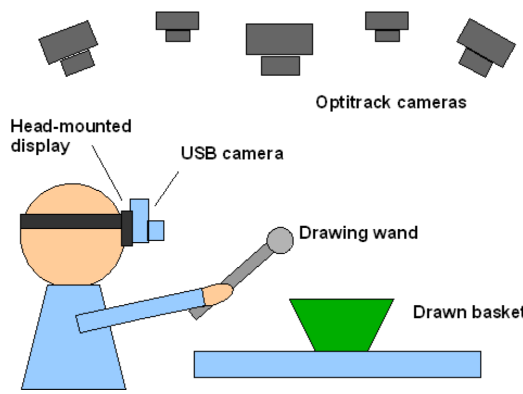

Figure 1. Diagram of Sketch System

Figure 2. User and Sketch System

SKETCHING APPLICATION

The sketching application has minimal functionality since the focus of this paper is the proof of concept of a real-time 3D sketching system with live 3D references. The tracking system captures the position and orientation of the user's wand and HMD. Direct3D is used to render freeform lines based on sampled wand position points. HMD position and orientation are used to configure the virtual camera to match the USB cameras that act as the user's eyes. DirectShow is used to capture video streams from the USB cameras attached to the HMD. The application can be run with one camera for each eye or a single camera for both eyes.

CALIBRATION

Because it is challenging to locate the exact view point of each USB camera, the virtual world is initially out of sync with the real world. Any small misalignment in orientation is amplified greatly in translation as distance is increased. To be able to synchronize the virtual world with the real world, it is essential to know the exact viewpoint of the user's eyes. This is difficult because the exact location of the USB camera lens can only be estimated. Lens distortion and uncertainties in the exact field of view of the USB cameras further complicates the issue. We explored the use of computer vision algorithms to help us resolve these issues. Computer vision algorithms are useful here because they do not depend on physical parameters to locate a view point. It only requires pictures taken by the USB cameras. We placed computer vision markers on a table top

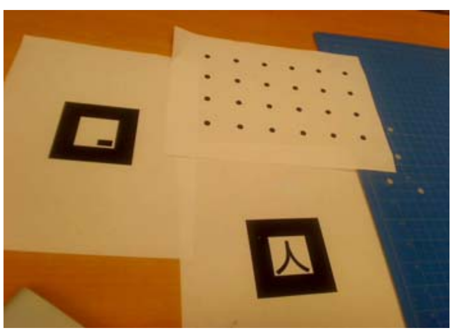

Figure 3. ARToolKit Markers

and took pictures of them using the USB cameras at the startup of the system. From the orientation, size and distortion of the pictures of these markers taken by the USB cameras, the computer vision algorithm is able to pinpoint the location of each USB camera's focal point. We used an open source package called ARtoolKit [4] for our computer vision algorithm. Calibrations were done so that camera distortion could be corrected. See Figure 3 for the marker we used. Because of lens distortion and field of view limitations of the USB cameras, further manual adjustments are still necessary after using ARtoolKit. To further calibrate our system, we tried to align rendered cubes with their physical cube counterparts by manually specifying additional offsets. Figure 4 shows rendered cubes (colored) matching up with physical cubes (green foam cubes) after manual calibration.

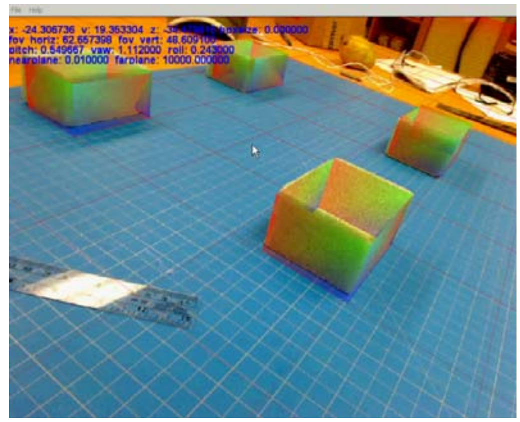

Figure 4. Rendered and physical cubes used for calibration

RESULTS AND FUTURE WORK

We successfully demonstrated a real time, immersive 3D sketching system that supports live 3D references. Freeform sketching by waving a wand feels natural and intuitive. Complicated 3D drawings can be made quickly without requiring a deep knowledge of modeling tools. But most importantly, the user can utilize live 3D references during the drawing process. This can be very useful if the user's creations are going to be fabricated using a rapid prototyping system. The sketching system is able to track the 3D reference to a reasonable degree of accuracy. Exactly matching the live reference and the 3D drawing in real time is difficult because of the limits of the tracking system. One other limitation of the system is the fact that the drawing is simply overlayed on top of the video stream. When drawing around a live reference, the reference may become obscured by the drawing. Making the drawing semi-transparent works well but future work may involve more sophisticated methods. Despite these limitations, the resulting system is a successful demonstration that real time 3D sketching with live references is not only feasible but also very useful. Figure 5 shows the sketching process of a basket to hold apples. The red sphere represents the tip of the drawing wand. The sketch strokes were then converted into a 3D-printable object using STLGenerator program [15].

Performance is another challenge in our demonstration system. Rendering latency becomes noticeable after drawing for an extended period of time. Future work includes implementing rendering optimizations, developing methods to reduce tracking error, developing a more sophisticated user interface and implementing sketching capabilities beyond drawing freeform lines.

CONCLUSIONS

While there have been several demonstrations of Virtual and Augmented Reality sketching systems, as well as sketch to manufacture [14], here we attempted to combine Head Mounted augmented reality and freeform fabrication technologies to begin examining the entire process. Our experiments so far indicate that calibration errors, lag time

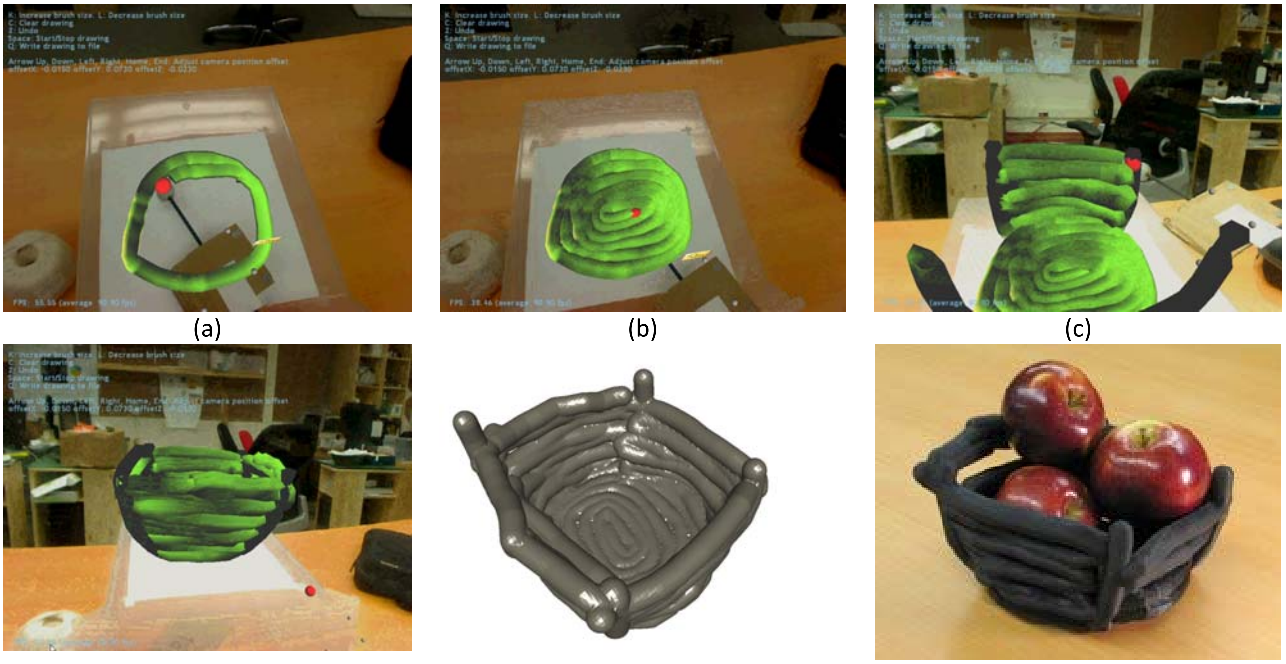

Figure 5. Sketching of a fruit basket: (a-d) sequence of frames as seen by the user through the HMD, (e) final manufacturable object (STL file), (f) basket manufactured using a rapid prototyping printer

and user fatigue hamper the freeform nature of this interface. While there are many applications of this technology beyond design [13], it is yet to be seen if these are merely technological challenges or are inherent usability issues that are fundamental to this mode of interaction.

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