Mid-Air Interaction with a 3D Aerial Display

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ABSTRACT

We present a re-imaged swept volume display enabling mid-air interaction with 3D floating objects without requiring a head-mounted apparatus. The presence of the volume is so strong that everyone reaches out to touch it, at which point the illusion is broken. To resolve this, we implemented interaction techniques to mitigate occlusion conflicts between the hand and virtual volume during direct manipulation. Our long term goal is to prototype direct spatial 3D manipulation techniques that highlight direct manipulation scenarios such as viewing 3D scans, previewing 3d prints, and product design visualization.

CCS CONCEPTS

Human-centered computing → Human computer Interaction → Interaction devices → Displays and imagers; *Redundancy*; **Hardware** → Displays and imagers

KEYWORDS

Volumetric display, mid-air image, mid-air interaction, 3D interaction, floating image.

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1 INTRODUCTION

We have designed a display that renders a mid-air 3D volume that you can interact directly with your hands without glasses or a head mounted apparatus. The feeling of presence of the volume is so strong that most people reach out to touch the volume but this presents interaction challenges because the light is occluded and the continuity of the illusion is broken. In our current prototype we present a solution to the occlusion problem which supports direct hand interactions inside the volume by adapting the volume to open up in the area where the hand is entering.

The hardware of the display is a 4 petal geometry designed specifically for the properties of optical re-imaging glass so that the volume can appear in free space.

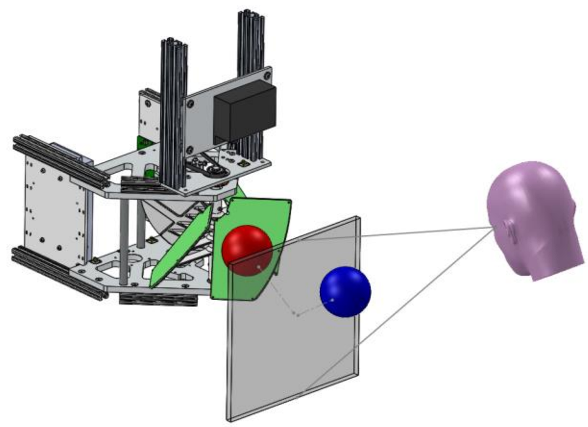

Figure 1: The concept of a swept volume display paired with re-imaging glass. True volume is red, virtual volume is blue.

Although previous systems have used re-imaging glass, no one has integrated it into a true volumetric display and implemented an initial user interface. The effect feels more closely aligned with a star wars rendering than a floating physical object. The “mid-air image” allows users to reach their hands into the volume and enables direct interactions with the interior which were previously not possible on other display systems. We believe that such mid-air volumes will be possible with more compact, static components in the near future and built the display to study interaction techniques as less bulky technologies mature.

2 SYSTEM DETAILS

In early prototypes of the system, the mid-air 3D effect was very strong but the display was noisy, not bright enough, and had a shallow depth of field. We collaborated with MistyWest, a design firm, to make the mechanical aspects of the design almost silent, reduce light interference, and commissioned Optecks LLC [1] to design a custom optical engine with a depth of field of 15 cm. The resulting volume supports 3D and parallax views within the 45 degree field of view limited by the Asukanet [2] imaging glass properties. Swept volume systems typically involve finding a balance between a set of tradeoffs between refresh rate, color rendering, volume size, resolution, and slice density. The volume is swept at 40Hz with 256 slices rendered per volume and rendered on a Vialux V-7001 DMD connected to custom hardware paired with an optical encoder. Initially the display had an RGB design but we currently limit the output to green due to brightness and flicker issues that occur when spinning the motor beyond 550 RPM. Our system refreshes at 4 volumes per second due to bandwidth limitations of USB 3.0, however the refresh rate is sufficient to approximate real-time interactions and study the user interaction modalities of mid-air volumes.

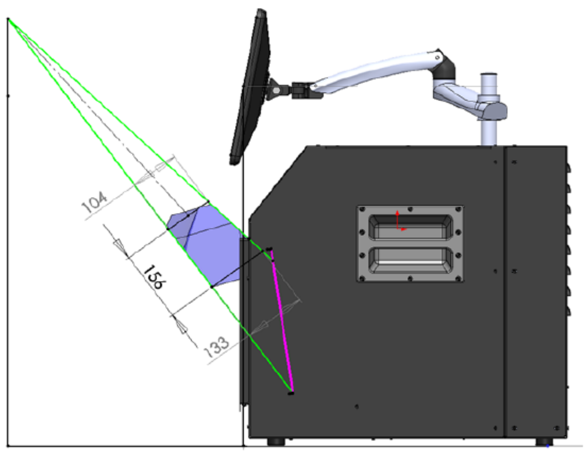

Figure 2: The size of the re-imaged volume in mm.

3 INTERACTION DESIGN

Having finalized the display hardware allowed us to shift the focus our development to three practical issues that will face mid-air auto stereoscopic displays in the future. (1) An intuitive user interface with haptic feedback is needed based on the position of the hands. (2) The volume needs to adapt when you reach into it so that the perception of depth is not lost due to occlusion conflicts. (3) Application areas that will directly benefit from spatial manipulation will require an intuitive means of transforming objects with the hands.

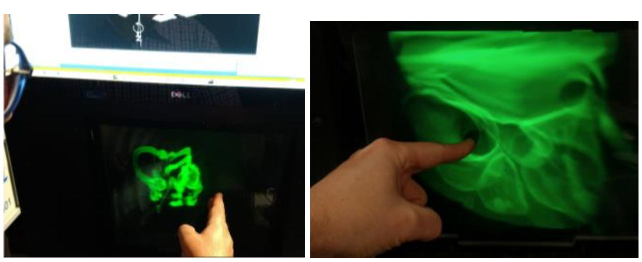

Figure 3: Over the shoulder view and up close view of the rendered volume.

In order to address these questions we started by building on prior research by Favalora [3] and Grossman [4] to visualize depth position and support multi-finger gestural interactions. We found that on our display the perceived depth of the model depends on how many open surfaces are in the model. If the model is closed, placing a finger inside the volume results in a perceived conflict between the finger and rendered volume. However placing a finger in an open model allows users to touch interior surfaces without any depth conflicts. Based on these observations we developed a hybrid interface based on distance. Far away, a depth ray with a menu appears, but as you reach into a volume this disappears and the front portion of the rendering opens.

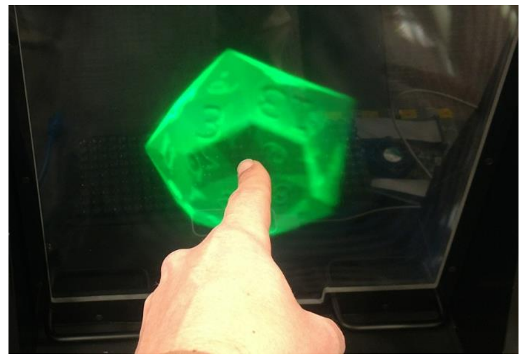

Figure 4: A volume opening as the hand enters it to accommodate the finger.

To study haptic feedback we are working closely with an ultrasonic array paired with a leap motion tracker. We utilize a custom array which has 9x28 emitters to support haptic feedback over a larger horizontal volume both in and around the rendering. In our application we add constant vibrations at the edges of the image volume and apply modal pulses on the palm when selecting objects and choosing menu items.

Literature on studies of the benefits of 3D displays by McIntire et al. 2012 [5] indicate that the most promising application areas will necessitate spatial manipulation and facilitate spatial understanding of 3D objects. For viewing 3D print previews and CAD models, users will need to examine a rendered object at scale, rotate views and select portions of the data based on its position in 3D space. We are currently developing a floating circular menu attached to the pointing hand that allows users to choose a transform mode with the other hand. We hope to receive feedback from SIGGRAPH attendees on this implementation and foster a conversation beyond “how does the display work?” to how we will interact with mid-air 3D displays in the future.

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