

A Tangible Interface for Creating Virtual Cutaways in Mixed Reality

Xuyu Li, Priyansh Jalan, and John Dingliana

Graphics and Vision Research Group, School of Computer Science and Statistics,
Trinity College Dublin

lix15@tcd.ie, jalanp@tcd.ie, john.dingliana@tcd.ie

Abstract. In this paper, we discuss work-in-progress research on tangible interfaces for interactive cutaway visualizations in Mixed Reality (MR). We present an approach that allows users to flexibly and intuitively define virtual cutaway geometry by directly interacting with real-world objects. Using hand movements the user physically traces the shape of the cutaway on an object, without the need for specialized input devices. Tangible interaction allows more accurate interaction and makes it easier for users to plan the placement and shape of required cutaways that fit the object. We developed a prototype demonstrator on the Microsoft HoloLens 2 and present the design and implementation details for such a system and discuss insights, gained from preliminary testing, that motivate compelling directions for future work.

Keywords: Mixed and Augmented Reality · Interaction · Visualization.

1 Introduction

Mixed Reality (MR) technologies provide users with experiences that blend digital information into the physical environment. However, robust spatial perception of the presented information is known to be challenging when multiple modalities (the real scene and virtual objects) are overlaid [4]. This is especially problematic in the case of applications such as anatomy visualizations, where an object is embedded within another. Merely drawing the internal structure over the outer object (referred to as *ghosting*) typically leads to ambiguous perception of relative depth [12]. One solution to this issue is cutaway visualization, a well-known technique used in engineering and medical illustration to reveal hidden internal structures within objects. Depicting the geometry of the virtual cavity (i.e. the walls of a cutaway volume) provides understandable visual cues that let users build a more robust mental model of the spatial arrangement of the internal and external structures. Unfortunately the specification of cutaways involves a 3D modeling task requiring some technical skill and authoring MR scenarios is generally challenging for novices due to limited established interaction tools currently available compared to desktop interfaces.

In this paper, we propose a system for allowing novice users, without extensive technical experience, to intuitively generate cutaway visualizations of

real-world objects in MR. Our main contributions comprise (a) the design of a pipeline that enables interactive creation of arbitrary-shaped cutaways using a tangible interface in MR, wherein the user defines the outline of the cutaway geometry by physically tracing their finger across the surface of a real-world object (b) analysis of a proof-of-concept prototype implementation on HoloLens 2 that demonstrates the feasibility and capabilities of such a system, but also providing insights into challenges and potential solutions for future applications.

2 Related Work

Cutaway visualizations have been discussed in computer graphics research for several decades as an alternative to ghosting [6, 7]. Some prior approaches procedurally define cutaways based on the underlying objects of interest [4, 12], utilizing basic template geometries such as cones [18], frustums [14] and other shapes [20]. Liang et al. [13] introduced a method allowing users to cut user-specified shapes in 3D polygonal meshes, which was applied to orthopedic surgery. Coffin and Hollerer [5] proposed a technique enabling users to define cutout shapes in general 3D scenes.

Immersive authoring, where the user interacts directly in the MR space in the process of creation, has been said to provide a more natural way of authoring elements of an MR scene [11]. Related to this, tangible user interfaces [10, 19, 22] that provide tactile feedback and direct manipulation have been demonstrated to be more efficient and intuitive compared to mouse-based or touch-based interaction [2]. Such interfaces have been discussed in the context of Virtual Reality [1, 16] as well as Mixed and Augmented Reality [9, 17, 21]. Some approaches, such as by He et al. [8], even go as far as using tangible immersive authoring to create elements of the augmented reality user interface itself. Meanwhile, Looser et al. [15] utilized tangible interaction to enable users to intuitively examine the interior of objects. However, their method is used to filter layers of virtual geometry rather than creating cutaways.

In this paper we propose an approach that extends upon existing works, by leveraging the paradigms of immersive authoring and tangible user interfaces for the intuitive authoring of cutaway visualizations of real-world objects in mixed reality. Unlike previous approaches for cutaways, which typically feature desktop modeling tools, our approach allows users to directly author cutaways in the mixed reality environment without specialized technical skills and eliminating the need to go back-and-forth between desktop modeling and real-world testing. Furthermore, physical interaction with real-world objects, by the users dragging their fingers across the real-world object’s surface facilitates a more intuitive, natural and evidently more precise generation of arbitrary-shaped cutaways.

3 Design and Implementation

The objective of our system is to enable non-expert users to easily and efficiently customize cutaway visualizations of physical objects, leveraging MR to explore

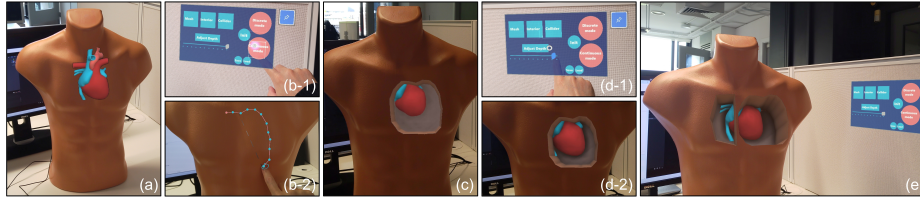


Fig. 1. An overview of system workflow: (a) scan and detect the physical object; (b-1) select mode and (b-2) define cutaway outline; (c) a cavity is generated once definition is complete; (d) change the depth of the cavity; (e) repeat for new cutaways.

virtual internal structures of interest. To achieve this, the system must accurately capture and track the surface geometry of the physical object that will be cut, track the user’s hand movements in real-time, and determine points of contact between the hand and object to define a cutaway outline. The resulting cutaways should fit in naturally and consistently with the real object surface.

We implemented a prototype system on the Microsoft HoloLens 2 using Unity. The Mixed Reality Toolkit (MRTK)¹ was used for hand tracking and system integration, and the Vuforia Engine² was employed for object tracking. The workflow of the system is shown in Figure 1 and described below. The accompanying video³ presents this workflow in more detail.

To define the cutaway outline, we developed an interactive process, which starts with the user pressing their finger on the physical object’s surface for a set duration (one second in our prototype). The distance between the finger and the surface is monitored to assess if the finger consistently stays within a small threshold range, with progress indicated by a circular progress bar. Next, the user drags their finger across the surface to define the cutaway outline. Discrete points traced out by the finger are generated at intervals, determined by a manually chosen threshold value, with smaller values resulting in higher resolution cutaways. Finally, the outline is considered complete when the finger arrives back within a threshold distance from the initial touch point.

For convenient drawing of coarser cutaways in larger-scale physical objects such as walls, we offer a discrete selection mode, where the user defines points on the outline by successively placing and lifting the finger across the surface. The user can choose between these modes using a user menu, which is projected onto a surface of the physical environment to preserve consistency with the tangible approach. In addition, the menu allows for other operations such as changing the depth of the cutaway cavity.

Contact detection between the finger and the physical object is achieved using Unity’s Physics module. This process requires two colliders: one based on a pre-captured mesh for the real-world object (for convenience, we obtain this

¹ <https://learn.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/mrtk2/>

² <https://developer.vuforia.com/>

³ <https://youtu.be/ywb5qWBbyeY>

using an off-the-shelf tool, Luma AI⁴), and one box collider attached to the top of the right index finger. The dimensions of the box collider are set to match the finger’s diameter to accommodate tangible interactions involving various angles of the finger, as shown in Figure 2(a).

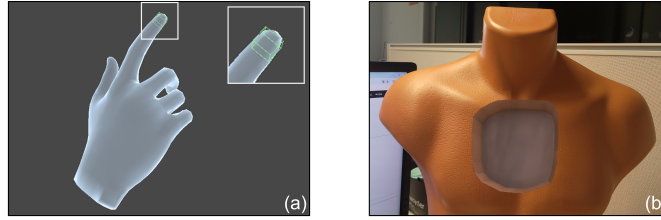


Fig. 2. System design components: (a) Box collider on the finger. (b) 3D Cavity.

Once an outline is obtained, we generate a cutaway manifold, a 3D representation of the surface of the real object that lies within the outline. The cutaway manifold serves as an *underlay* mask for rendering, essentially a portal through which users can see the virtual inner objects. This is achieved by employing the stencil buffer and stencil test, as in the approach of Looser et al. [15]. Then we need to model the geometry of the 3D cavity inside the physical object that is exposed by the cutaway. The floor of the cavity is defined by internally extruding the manifold by a pre-specified distance, which can be adjusted by the slide in the tangible user interface. The direction of extrusion is calculated by averaging the normals of the manifold mesh. The walls of the cavity are created by connecting corresponding pairs of vertices from the floor and manifold.

To ensure seamless integration of the cavity with the physical object, we color the cavity based on the real object’s surface color. We apply a color gradient that subtly decreases in saturation and brightness towards the floor of the cavity, which serves to make the surface stand out more prominently, increasing the perception of the virtual object as a hole rather than an overlay. The overall rendering result is demonstrated in Figure 2(b).

4 Analysis and Conclusions

We tested the proposed system using two anatomical MR scenarios: a physical mannequin *Chest* model embedded with a virtual animated heart, and a *Head* model embedded with a static 3D brain. Figure 3 compares user-generated cutaways in the two scenarios, against a naive overlay of the internal objects rendered over the real objects. The visual metaphor of the cutaways is designed to provide a stronger cue that the virtual object is embedded within the real

⁴ <https://lumalabs.ai/>

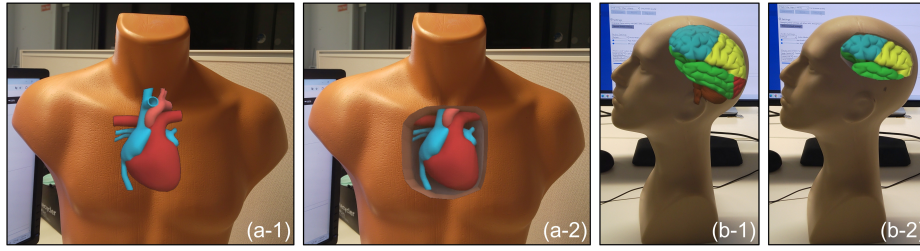


Fig. 3. Rendering results. (a) The *Chest* scenario. (b) The *Head* scenario.

object. We conducted preliminary evaluations of the prototype of the usability and technical performance of the system with respect to these two test scenarios.

4.1 Usability

Using our system, novel cutaways can easily be generated within a few seconds of interaction. Authoring directly within MR has advantages over a desktop modeling tool in that cutaways are created directly in world space without worrying about how they will be later scaled or placed in the scene. Physical contact also stabilizes hand movements and improves spatial perception, potentially leading to more precise interactions compared to “mid-air” gestures common in MR. In a preliminary pilot study to test this, we asked participants to trace predefined target cutaway outlines of varying shapes projected onto the surface of the *Chest* model in two ways: (i) using mid-air gestures over a purely-virtual chest, and (ii) using our tangible system with a physical chest, as shown in Figure 4(a). As a measure of accuracy we computed the Hausdorff distance (HD) between the user-traced outline and the target outline.

Five participants were recruited opportunistically from our research group, all male, aged 24-29 who had some familiarity with 3D modeling, mixed reality and gestural interactions. The average HD, over 100 trial runs and varying target outlines, was found to be 7.5 mm for lines traced using mid-air gestures compared to 6.3 mm using the tangible method, an apparent improvement of 16%. For more details see Figure 4(b).

In future work we plan to conduct deeper user studies, with more varied participants of varying expertise levels and a larger range of scenarios to explore if such improvements generalize consistently and also inform how we could improve the system further. Additionally, efficacy and intuitiveness of the system could be tested using established methodologies from the related literature, such as the System Usability Scale [3].

4.2 Technical Performance

On the HoloLens 2, the system achieved real-time performance for both of the test scenarios. The *Chest* scenario (10k vertices, 15k triangles) ran at an average

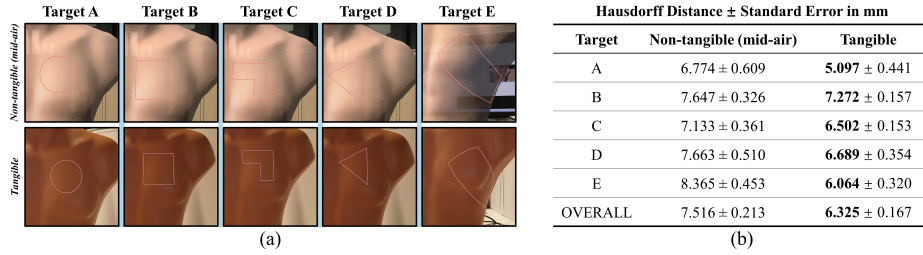


Fig. 4. Pilot study. (a) Users traced target outlines of varying shapes using mid-air gestures (top) and our tangible system (bottom). (b) Hausdorff distances between user drawn lines and the target, averaged over 10 trials per target.

of 56 frames per second (fps), while the *Head* scenario (161k vertices, 277k triangles) ran at 43 fps.

More realistic illumination effects could further enhance spatial perception, but some advanced techniques were precluded due to performance limitations of the HoloLens 2 hardware. Rendering techniques such as ambient occlusion reduced the framerate in our prototype to 20 fps, but this could be improved through better optimization. Since the models are only used as tracking and interaction proxies, higher framerates could be achieved without significant visual degradation by reducing the mesh resolution as needed.

4.3 Other Future Improvements

Tracking in our prototype system, using off-the-shelf functionalities of Vuforia and MRTK, exhibited some inaccuracies and slight lag, particularly with very fast user movements. More efficient techniques from recent literature should be investigated to optimize this in the future. We plan to deploy and test our system on newer devices, such as the Quest 3 or Apple Vision Pro.

In our prototype, we used pre-digitized models of the outer object for interaction and tracking purposes. Future solutions should allow this to be done at runtime. Spatial mapping tools such as in MRTK currently lack precision to capture fine-grained details, but we expect this to improve with hardware and software developments. We plan to improve the customizability of the cutaways through interactive options for adjusting, fine-tuning and smoothing cutaway boundaries after initial generation. Solutions in future should provide mechanisms for calibrating the position and scale of the internal object and for handling deformable physical outer objects such as real human bodies.

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