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Real-Time Exploded View Animation Authoring in VR Based on Simplified Assembly Sequence Planning

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Abstract

In this paper, we present an animation authoring tool, capable of automatically generating an exploded view of assemblies in real-time. 3D user interfaces in virtual reality are used for controlling the explosion distance of parts, as well as other metrics affecting the explosion direction and order. The methods used are based on assembly sequence planning and employ an assembly-by-disassembly approach, requiring no additional information about parts other than their geometry and position in the assembled state. The computation times for five assemblies of different complexities are presented, tested on a standalone virtual reality device.

Index Terms: Human computer interaction (HCI)—Virtual reality; Computing methodologies—Computer graphics—Animation Human computer interaction (HCI)—Visualization systems and tools

1 Introduction

In recent years, the use of virtual reality (VR) for industrial applications such as VR training and product demonstration has increased, which in turn has generated a need for better tools supporting these use cases. One of the common challenges when presenting a product in VR for training or demonstration purposes, is the creation of exploded view animations, often used for their ability to convey the spatial information in an assembly, such as the relationship between parts, enabling viewers to mentally reassemble the model [6]. With the correct order of part animations this also enables step-by-step assembly instructions in a way that static images cannot.

Creating an exploded view animation involves finding the direction, order, and distance of parts in the assembly, and today, creating these animations is largely still a manual process performed by graphics artists. There are existing 3D modelling tools that can assist in this process, but they still require user input to generate even simple animations [4]. Previous studies have also proposed solutions for automatically generating exploded views, but they are computationally expensive and time consuming, and often rely on additional information regarding the nature and relationship of parts, such as CAD data [1].

In this work, we present a VR authoring tool capable of automatically generating exploded view animations of heterogeneous 3D assemblies in real-time on a standalone VR head-mounted display (HMD). The calculation of direction and order is based on algorithms from the assembly sequence planning (ASP) domain and the calculation of distance is based on an animation boundary. In order to achieve real-time computation times, the parts and assemblies are simplified to their minimal Oriented Bounding Box (OBB). After being presented with the initial animation, users are able to modify the distance of parts by adjusting the animation boundary. It is also possible to modify the direction and order by changing the priorities of ASP-based blocking tests performed, or changing the rules for initial intersection between parts. These inputs enable users to correct some of the technically inaccurate results that may occur due to the simplified methods.

2 Related Work

The automatic generation of exploded views of 3D models has been studied in several previous works, and has traditionally been based on algorithms and methods from the ASP domain [1, 3, 7, 11]. While these methods have been shown to be precise enough to produce assembly instructions, they often rely on 3D CAD data and are computationally expensive, taking several minutes to calculate just the explosion directions for even simple assemblies [2, 6].

Some studies have explored the creation and use of exploded views in augmented reality (AR) [6, 8, 10]. The layouts in these proposed solutions were not computed in real-time, however, but in a pre-processing step.

Ai et al. [2] presented a solution for computing and presenting an exploded view of an assembly on mobile devices. The explosion directions of parts, however, are based on a spherical 3D probe tool, resulting in directions from the center of the probe to the part, similar to previous studies [9].

3 Methods

The calculations of direction and order are an iterative process during which each part in the assembly is subjected to up to three tests, a longest axis test (LAT), a neighbour separation test (NST), and an assembly centroid test (ACT). Similar to previous studies in ASP, we are using an assembly-by-disassembly approach [5], starting with an assembled model and removing a part when a test succeeds until all parts have been removed. The three tests implemented involve finding candidate explosion directions and then testing for intersections with the other remaining parts in the assembly. In order to achieve real-time performance, the parts are simplified to their OBB, and the set of possible directions for a part is reduced to the six directions of its local axes ($\pm X, \pm Y, \pm Z$), similar to previous works [6, 11]. The candidate directions are tested by moving the OBB and checking for intersections using the Separating Axis Theorem (SAT).

LAT If the OBB of the part is at least 70% longer in one axis than in the others, the directions of that axis are candidates, prioritizing the direction leading away from the centroid of the assembly.

NST The closest neighbouring part is found by first checking for intersection using the SAT. In case of no intersection, the distance is the smallest possible distance between the two OBBs. In case of intersection, if the penetration value is smaller than a certain threshold, the distance is the negative of the penetration value. From empirical testing, this threshold is set to 0.7% of the length of the OBB in the axis of least penetration. The candidate direction is the separating axis from the neighbour with the smallest distance, or in case of intersection, the axis of least penetration.

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Table 1: Calculation times for exploded view directions and distances for different assemblies.

Assembly ID	Parts	Direction time (ms)	Distance time (ms)
1	11	1.11	0.15
2	18	32.27	0.31
3	24	4.77	0.49
4	36	11.63	0.53
5	256	445.91	27.22

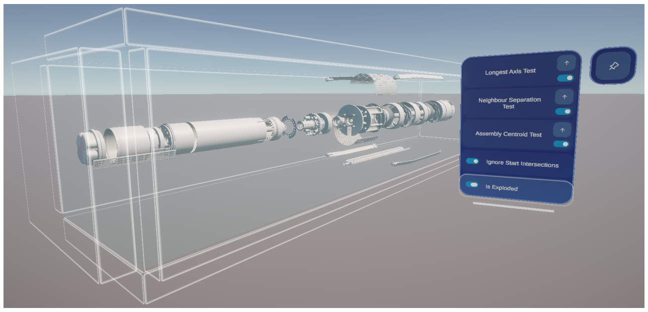

Figure 1: An exploded view of an assembly automatically generated, with the explosion distance constrained by the animation boundary.

ACT The candidate direction is the direction of the local axis of the OBB that is closest to the direction vector from the centroid of the assembly to the center of the OBB.

If a test succeeds the part is removed and if it fails the next test will be executed. If all tests fail the part could not be removed in the current iteration and will remain for the next iteration. The order assigned to a part is the iteration during which it was removed.

The order the tests are executed can affect the final exploded view, as it may be possible for more than one test to succeed during an iteration. Therefore, a simple UI is provided enabling users to set the priority of tests and recalculate the direction and order of parts. Another setting provided to users is the option to ignore intersections that parts may have in their initial state during the first iteration, as this can also affect the direction and order of parts.

Distance As additional user input, an axis-aligned bounding box (AABB) is generated, that can be adjusted by the user in VR by manipulating the six faces of the AABB. For a part, the maximum distance is determined by the ray intersection between the disassembly direction and the AABB, and the actual distance is calculated based on the parts intersecting when moved and their order, so that parts are evenly spaced in the area available.

4 Results and Discussion

A prototype was developed in the Unity game engine and tested on a Meta Quest 2 VR HMD. The prototype was tested on five assemblies of different complexities. The assemblies, their number of parts and their computation times in VR are presented in Table 1. An exploded view of assembly 4, with the animation boundary and settings panel, is shown in Fig. 1.

It can be seen that the computation times increase with the number of parts in the assembly. This is to be expected and is also the case for previous studies using similar methods [7]. It can also be seen that the computation of directions for assembly 2 takes significantly longer than for assembly 3 and 4, even though they have more parts. This is likely due to the iterative nature of the ASP algorithms, and that the parts in assembly 2 are more difficult to remove from the assembly due to their design.

All the computation times presented are in the millisecond range, enabling a real-time authoring workflow. For the computation of distance, only the largest assembly would have to be split across multiple frames, even if assuming a target frame rate of 120 Hz.

5 Conclusion and Future Work

The exploded view animation tool presented in this paper is capable of automatically determining direction, order and distance for assemblies in real-time on a standalone VR HMD. The calculation times are in the order of milliseconds, even for large assemblies of more than 200 parts. In order to correct technical inaccuracies in the part animations, simple VR controls are provided for a human-in-the-loop authoring process.

In future work, we intend to make the distance calculation aware of obstacles in the virtual space [10], and support part hierarchies and sub-assemblies [7, 12]. We would also explore other user input that may be provided, such as modifying the layers that parts are partitioned into or adding rotations to the part animation. Ultimately, we will evaluate our proposed solution during a comparative user study, comparing the layout, computation times and authoring workflow with other automatic or semi-automatic tools available.

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