FlexiPrim: Deformable Primitives for Guiding 3D Painting in Virtual Reality

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ABSTRACT

The goal of this study is to support efficient and consistent three-dimensional (3D) painting in virtual reality (VR) space. For this, we propose the use of deformable primitives as a construction guide in the early stages of 3D painting and introduce FlexiPrim, consisting of two primitive types, cuboid and ellipsoid. The user can deform FlexiPrim by manipulating the control points in VR space. We conducted a user study to compare FlexiPrim with traditional Guide-Objects in OpenBrush, where the latter has an automatic snapping function. As a result, we found that the proposed method enables the creation of construction guides consisting of curved elements, and participants provided positive feedback on the subsequent rough sketch using the FlexiPrim as guide.

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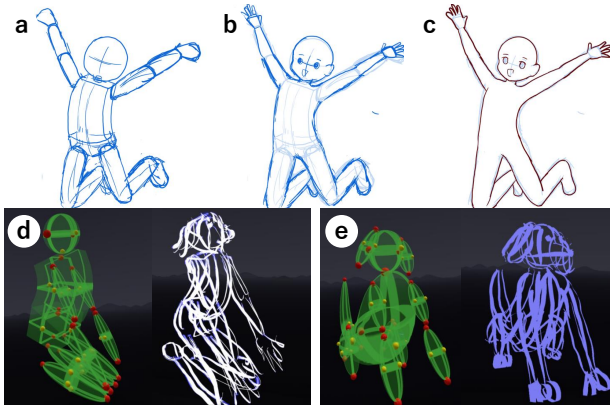

Figure 1: The early stages of 2D illustration typically comprise a construction guide (a), rough sketch (b), and clean curves (c). We propose the use of deformable primitives, FlexiPrim, as a construction guide for 3D painting in VR (d, e).

1 INTRODUCTION

Drawing construction guides and rough sketches is essential for creating consistent and well-structured illustrations in two-dimensional (2D) illustrations. Construction guides (also termed construction lines) are drawn by sketching primitive shapes such as rectangles or ellipses to roughly specify the position, size, and composition of each object (Fig. 1a). Subsequently, rough sketches are drawn over the construction guides to add more concrete shapes and details (Fig. 1b). The illustration is completed by refining the rough sketches into clean line-drawings (Fig. 1c) and adding colors. With the increasing availability of virtual reality (VR) devices, three-dimensional (3D) painting in VR is becoming increasingly popular. A 3D construction guide tool that allows the user to quickly specify various 3D shapes is required for achieving efficient and consistent 3D painting.

Many methods have been presented for 3D painting in VR environments. For instance, VRSketchIn [1] introduces a 2D tablet in VR space to support a stable painting process, whereas HandPainter [2] enables users to draw 3D strokes using their non-dominant hand as a canvas. Turkmen et al. [4] proposed EyeGuide and EyeConGuide, which display grid lines in the 3D VR space based on the user's gaze direction and hands to guide 3D painting. However, these approaches primarily focused on supporting the 3D painting process, whereas providing a construction guide was not considered. OpenBrush [3], an open-source VR painting application, provides *Guide-Objects* with automatic snapping functions that can serve as construction guides. However, this tool only supports the simple scaling of primitives and cannot deform them, making it difficult to represent construction guides with curved elements, as shown in Fig. 1.

The goal of this study is to support efficient and consistent 3D painting in VR. To this end, we propose the use of deformable primitives as a construction guide and introduce FlexiPrim, which the user can freely stretch and bend in VR space. FlexiPrim supports two types of primitives: ellipsoid and cuboid. The user can tune the position, orientation, scale, and axis curve by manipulating control points. During the painting process, the user first places multiple primitives to roughly specify the approximate shape of the target object, and then draws 3D strokes using the primitives as guides. Since FlexiPrim allows both bending and stretching, it can represent complex shapes (Fig. 1).

2 METHOD

FlexiPrim consists of two types of primitives: cuboid and ellipsoid. Each primitive has an axis curve and control points for manipulation. The axis curve defines the central axis of the primitive and is not visible to the user during actual use. The red control points, placed at both ends of the axis curve, are used to deform the primitive. By grabbing and dragging one of the points, the user can

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modify the position and orientation of the primitive. By grabbing and dragging both points, the user can stretch the primitive. The primitive can be smoothly bent by grabbing both points and twisting the right-hand controller (Fig. 2ab). The user can also modify the scale of the primitive in the direction orthogonal to the axis curve by manipulating the yellow control points.

FlexiPrim provides visual guidelines to support subsequent 3D painting; three orthogonal rings are displayed on the ellipsoid, whereas three orthogonal midlines are visualized across the faces of the cuboid, as shown in Fig. 2. Grasping the overall structure during 3D painting within VR space is often difficult because the user typically sees only a limited part of the drawing at a time. The guidelines provide crucial visual cues for grasping the global structure and achieving a balanced composition. The guidelines are also useful when drawing additional objects, such as eyes and a mouth, on the surface.

The axis curve is represented by a quadratic Bézier curve: $\mathbf{c}(t) = (1-t)^2\mathbf{p}_0 + 2t(1-t)\mathbf{p}_1 + t^2\mathbf{p}_2$, where $t \in [0,1]$ is a parameter, and $\mathbf{p}_0$ and $\mathbf{p}_2$ correspond to the positions of the two red control points. $\mathbf{p}_1$ is the middle control point, which is initially placed at the midpoint of $\mathbf{p}_0$ and $\mathbf{p}_2$, and the user controls the displacement along the y-axis of the local coordinate system through a twisting action (Fig. 2c). Skinning is used to deform the primitive shapes along the axis curve. The proposed method was implemented as an extension of the OpenBrush platform to leverage various existing painting tools.

3 USER STUDY

The effectiveness of the proposed method was evaluated through a user study in which FlexiPrim was compared with Guide-Objects, having snapping functions, in OpenBrush. After a brief tutorial, each participant practiced a VR painting task consisting of (i) placing a construction guide and (ii) drawing a rough 3D sketch using each method: FlexiPrim and Guide-Objects. Each participant then performed the VR painting tasks four times by drawing two reference illustrations using each of the two methods. The reference illustrations, a sitting woman and sitting dog, were provided in 2D format (Fig. 3). When drawing the woman, the participants began with a template in which the primitives were arranged in a T-pose, whereas when drawing the dog, they started with primitives arranged in a quadruped pose. The order of the two methods was counterbalanced across participants. After completing all tasks, the participants answered a system usability scale (SUS) questionnaire and an additional questionnaire.

The participants of the user study were six university students; two participants had prior experience in 2D illustration, whereas the others had little experience in illustration. Fig. 3 shows the construction guides and rough sketches created by the participants, indicating that FlexiPrim enabled the participants to represent an arched back by deforming a primitive. The average SUS scores were 62 for FlexiPrim and 68 for Guide-Objects. In response to the question "Which tool made it easier for you to place the construction guides, FlexiPrim or Guide-Objects?", two participants chose FlexiPrim, whereas four selected Guide-Objects. This result suggests that although FlexiPrim enables more flexible deformations, the manipulation is more complex. In response to the question "After placing the construction guides, which tool made it easier for you to draw rough sketches, FlexiPrim or Guide-Objects?", five participants chose FlexiPrim, whereas one selected Guide-Objects. This result can be explained by the fact that FlexiPrim allows for more flexible painting as it does not automatically snap strokes to the primitive.

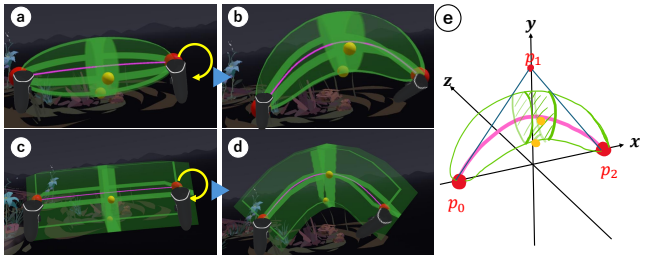

Figure 2: Two types of primitives and their deformation (a–d). Pane (e) shows local coordinate system.

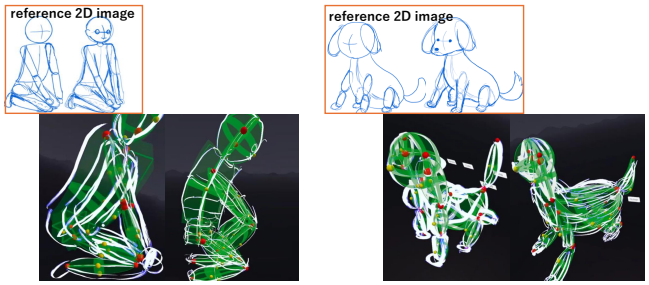

Figure 3: 3D paintings created by some participants. Each pane provides a reference 2D image at the top left. White curves are rough sketches.

4 CONCLUSION

This study proposes the use of deformable primitives as construction guides in the early stages of 3D painting in VR space and introduces flexible primitives, FlexiPrim, which the user can freely stretch and bend. Comparative analysis of FlexiPrim and the traditional Guide-Objects provided in OpenBrush through a user study demonstrated that FlexiPrim allows participants to create a complicated construction guide by bending primitives. The user study highlighted a drawback wherein the user interface of the proposed method was considered less intuitive (SUS = 62). The development of simpler interactions for specifying diverse construction guides remains an important future work.

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