SmartSweep: Context-aware Modeling on a Single Image

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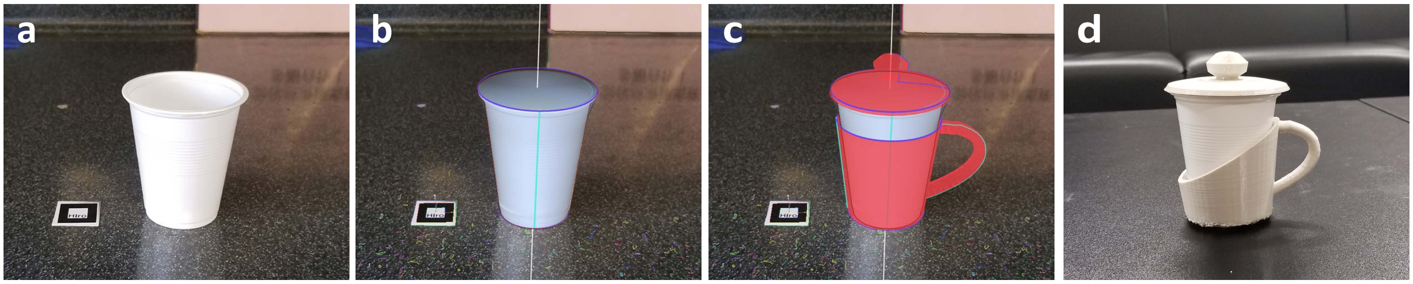

Figure 1: Starting with an input image (a), users can easily reconstruct the context (b) and create complementary models (c) using our tool. The models are thicken outwards, cut (for aesthetics) and printed without any scaling (d).

CCS CONCEPTS

• **Human-centered computing** → *Interactive systems and tools*;

KEYWORDS

sketch-based modeling, in situ modeling

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1 INTRODUCTION

With the wide accessibility of consumer-level 3D printers nowadays, personalized fabrication, especially complementary object design, has attracted more attention of people. However, most supportive systems have been focused more on 3D inputs [Chen et al. 2015; Weichel et al. 2014] and use less 2D information, even though images are easier to obtain than 3D objects in practice. Besides, even with a reference 3D model, it still requires tedious manual work to create a complementary object.

In this paper, we present a new image-based tool to quickly create complementary parts for existing physical objects, which we term *SmartSweep*. The key idea is to detect and utilize the features of existing context to augment the modeling procedure. Therefore, we firstly apply an image-based modeling technique to reconstruct the object and thus obtain its basic geometric information. Furthermore, we analyze the context to get high-level features like symmetry and provide specific operations based on them. Our work is similar in spirit to Modeling-in-context [Lau et al. 2010], a system that allows users to create complementary objects by sketching and annotating properties on a photo. However, it only takes the photo as a reference for users, without any explicit usage of the image information. In addition, the system requires a complete wire-frame and manual annotations as input in order to generate a 3D object, which is tedious and unintuitive for users. Comparatively, we claim the following advantages of our approach:

- We partly reconstruct the physical object from the reference image, which provides more details to conveniently generate complementary parts with real size.
- The contextual features are automatically detected and utilized in the modeling procedure, which makes our tool smart and convenient to use.

2 METHODOLOGY

Our system is based on sweep modeling, so users only need to create a profile and a trajectory to generate a model. The workflow is as follows. First, users take a photo including a reference object and a fixed-size AR marker, laid on the same flat surface[1] (Figure 1a). Then, users reconstruct the object in 3D by tracing out the profile and sweeping (Figure 1b). Our system analyses the reconstructed context and provides a few operations based on the detected features, with which users can easily create complementary parts (Figure 1c). As more parts are added, the contextual features are continually updated to support the subsequent operations. Figure 1d shows the fabricated result.

Context Reconstruction. We adopt the 3-Sweep [Chen et al. 2013] method for reconstruction. The concept is to extract outlines from image and snap the base profile's 2D projection to it during sweeping. However, some assumptions of this method reduce the precision. For example, it sets the center of profile as the middle of two contour points, while the actual location should be farther due to perspective viewing. Since most man-made objects have a straight central axis, we simply fix the central axis and only adjust the diameter.

Besides in the original method, the profile is defined by user's gesture only, yet we need to snap the profile to the image for higher accuracy. The challenges involve 1) finding the correct corresponding points in image; 2) balancing the matching of 2D projection and the regularity of the resulted 3D shape. Since the orientation of profile is fixed in our case, we can get a 3D curve by back-projecting a 2D curve to the X-Y plane. However, it may not produce a regular shape, since a minor offset in 2D can result in a noticeable disparity in 3D. In our method, we compute the 3D profile via iterative optimization.

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[1] In order to calculate the real size of the object, we constrain the base profile of the object to be coplanar or parallel with the marker's X-Y plane.

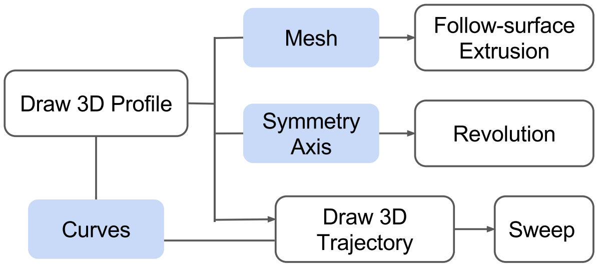

Figure 2: The pipeline for modeling, showing the operations (in white) and associated contextual features (in blue).

Taking generalized cylinders for example, we first use the input 2D ellipse to find corresponding image edges, and define a 3D circle by back-projecting the 2D center and major axis to the X-Y plane. Note that this initial circle might be deviated from the actual position. We then iteratively translate and scale the 3D circle to minimize the error between its 2D projection and the corresponding image edges. This method can be generalized to any profile shapes as long as the 3D regularity is detectable.

By default, the starting profile is projected on the X-Y plane. If the ending profile is on the X-Y plane instead, the reconstructed model is a uniformly scaled and translated version of the actual object. For this case, we compute the screen coordinates of the ending profile and back-project it to the X-Y plane to get the real position and the scale ratio to transform the model.

3D Curve Creation and Analysis. Since the new object is highly related to the reference object, we assume that its profile and trajectory are likely to lie on some existing plane or model surface. Therefore, we create 3D curves by projecting 2D strokes onto a 3D plane or the underlying geometry. As each planar curve in the scene is associated with a plane, users can directly click on it to select its base-plane, or make a cut gesture on the curve to create a perpendicular plane along the cut. Since sweep trajectory is generally perpendicular to the profile, we also provide a shortcut to align the camera with profile's plane, from which view users can draw the trajectory with less perspective distortion.

The generated 3D curves, however, are usually distorted because of free-hand input or perspective drawing. Inspired by works on sketch beautification [Fišer et al. 2015], we treat planar curves as 2D curves on their base plane and rectify them with a few geometric constraints: 1) endpoint-snapping, where the endpoints will be joined if they are close enough; 2) perpendicularity of polyline segments, where the inner angles of polyline are set as 90 degrees if they are nearly right angles; 3) segment length equality, where the polyline segments are equalized if their length are close. In addition to these individual rectification, we also exploit the context, namely the previously created curves, to beautify the new inputs, which will be explained below. Based on the rectified result, we check if the curve has rotational or reflectional symmetry, which provides high-level information of the shape.

Context-aware Operations. Figure 2 illustrates the operations for modeling, including:

- **Sketch Beautification** Given a new curve, we identify the existing curves on the same plane or on a parallel plane, compute the distance of their centers, and measure their shape similarity using the method of Shao et al. [2011]. If the distance between the curve center and an existing curve is smaller than a threshold, the new curve is aligned. If there exists a curve similar to the new one, we replace the new curve by offsetting the existing curve.
- **Follow-Surface Extrusion** In addition to conventional sweeping, we also provide an extrusion operation where the profile is swept over the surface of the reference model. In another word, we keep the distance between the profile and the encircled object consistent during sweeping. This allows users to create shell-like supplement of the reference objects. The system automatically switches to the follow-surface extrusion if the sketched trajectory is nearly parallel to a model's silhouette. Users can also explicitly activate this operation and drag the profile along a mesh.

Figure 3: A corner bumper created using our tool.

- **Revolution Axis Proposal** Since the rotational symmetry has been detected during analysis, users can draw a profile near a visualized symmetry axis and build a model through revolution. The profile is created by projecting 2D stroke to the minimum-skew viewplane.

3 RESULTS

Figure 1c shows a cup lid created via revolution, a cup holder created via follow-surface extrusion, and a handle created via conventional sweeping. Figure 3 is another example. We compare the real size and the reconstructed size of the cup in Figure 1 below, which are very close. However, it may sometimes be hard to predict the real size when sketching new models, causing lightly large gap between the cup and the holder (Figure 1d).

	top boundary	bottom boundary	height
real (cm)	22.93	14.14	8.0
reconstructed (cm)	23.27	14.57	8.31

4 FUTURE WORK

We plan to quantitatively evaluate the precision for fabrication and the usability of our system to validate its practicability. We would also like to incorporate multiple objects for complementary object design, like making a cup holder which can be attached to a table.

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