3D Sketching for Multi-Pose Products

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Abstract
During the initial stage of design, 2D perspective sketching is an essential tool for designers. However, for products with multiple moving parts that assume multiple poses during usage, 2D perspective sketching can be painstaking and time-consuming. In this study, we show that such multi-pose products are prevalent in the context of product design and therefore propose a 3D sketching system tailored to multi-pose products. Our system enables designers to sketch 3D curves that can be freely posed and easily viewed from different directions; it makes sketching chained moving parts and propagating changes to different poses and perspectives effortless. We show that, with interactions closely resembling traditional 2D perspective sketching and the physical manipulation of an articulated object, designers can focus solely on ideating, iterating, and communicating multi-pose product concepts during the initial stage of design.

Author Keywords
Product design; 3D sketching; parting; rigging; posing; pen; touch; gesture

CSS Concepts
• Human-centered computing~Human computer interaction (HCI)~Interaction techniques • Computing methodologies~Computer graphics~Graphics systems and interfaces

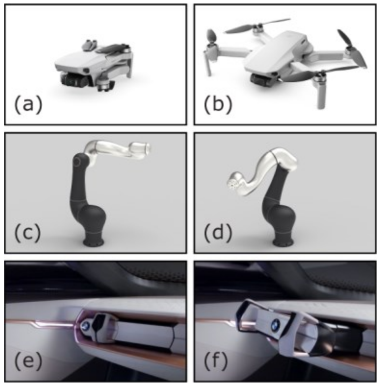

Figure 1: There are many multi-pose products that change poses during usage, such as (a, b) an aerial drone, (c, d) a collaborative robot, and (e, f) an autonomous vehicle. In the early design stage, drawing these concepts solely with 2D perspective sketching can be painstaking and time-consuming.

Introduction

2D perspective sketching is a simple yet expressive technique. It allows designers embarking on new design projects quickly and easily capture the fleeting idea of the form and function of a product before committing to a more elaborate medium of expression, such as 3D CAD modeling. However, there are cases in product design in which the 2D perspective sketching falls short and a higher level of functionality is needed.

One such case is designing a product that has multiple moving parts and takes multiple different poses during usage: an aerial drone with a folding mechanism for portability (Figure 1a, b [5]); a robot arm with six or more rotational joints for full spatial mobility (Figure 1c, d [6]); and a car with interior and exterior features that configure themselves in accordance with different driving modes, such as manual driving and autonomous driving (Figure 1e, f [3]).

Even for highly-skilled designers, drawing these products in different poses and different perspectives can be painstaking and time-consuming. In particular, drawing a moving part that moves against another moving part, or propagating a change made in one pose and perspective to all other poses and perspectives can be challenging. Such difficulties can hinder the rapid ideation and iteration that must take place during the initial stage of design.

We thus propose a 3D sketching system for multi-pose products. Using our system, designers can sketch 3D curves that can be freely posed and easily viewed from different directions (Figure 2). Our system makes sketching chained moving parts and propagating changes to other poses and perspectives effortless. Through interactions closely resembling traditional 2D perspective sketching and the physical manipulation of an articulated object, designers can focus solely on ideating, iterating, and communicating multi-pose product concepts during the initial stage of design.

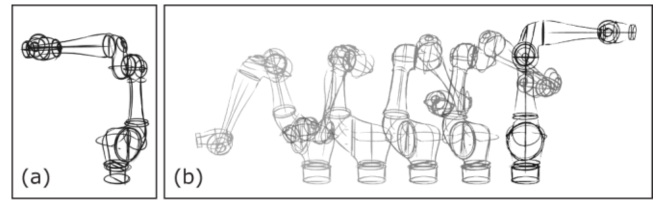

Figure 2: Using our 3D sketching system for multi-pose products enables (a) a static 3D sketch with chained moving parts to be (b) easily posed, allowing designers to focus on ideating, iterating, and communicating multi-pose product concepts.

Related Work

3D sketching refers to interactive techniques and systems that enable the user to intuitively express 3D forms through pen drawing input. In particular, 3D sketching based on traditional 2D perspective sketching techniques, such as repeated sketching in multiple perspectives [1, 11] and setting up reference 3D planes before sketching on them [2, 15, 16], has proven to be very powerful in the hands of professionally-trained designers. Our system uses plane-based 3D sketching [15, 16] for its ease of use and implementation.

Some interaction techniques and systems provide intuitive means of static sketching and making them more kinetic. Some parts of 2D sketches can be made into interactive objects, and pen-based gestures and widgets can be used to specify desired motions for these objects [4, 12, 13]. Alternatively, the system can assist the user in the construction of a kinetic 3D model based on multiple 2D sketches [19].

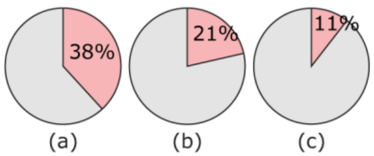

Figure 3: Among 1,669 products surveyed, (a) 38% had at least one moving part, (b) 21% had multiple moving parts, and (c) 11% of them had moving parts that moved against other moving parts.

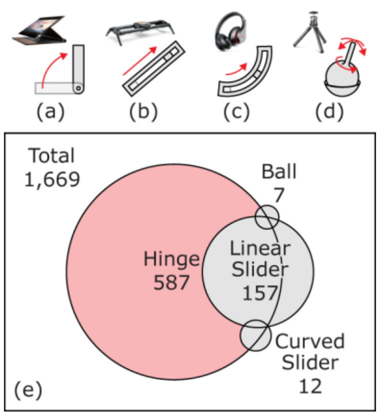

Figure 4: Across all 637 multi-pose products, only 4 types of joints were observed: (a) hinge joints, (b) linear slider joints, (c) curved slider joints, and (d) ball joints. (e) A Venn diagram, showing the number of times these joints appeared in the surveyed products. Shaded area (pink) shows that a large portion of products rely entirely on hinge joints.

Although a study has applied similar ideas to 3D sketching to specify optimization parameters for a generative algorithm [14], we focus on making 3D sketches more kinetic to facilitate ideation and iteration on multi-pose products.

Survey

To estimate the prevalence of multi-pose products and the types of movements they typically feature, we surveyed all 1,669 products that received the Red Dot Design Award 2019: Product Design, an internationally recognized design award that selects for high-quality across all product categories, including furniture, appliances, gadgets, cars, and even industrial tools.

We set four criteria for what makes a given product a multi-pose product: first, the product has at least one moving part; second, the moving part is rigid (i.e., not textile); third, the movement is structural (i.e., not clickable buttons); and fourth, the movement is nondisruptive (i.e., neither assembly nor disassembly). In addition, for each product that satisfied the multi-pose-product criteria, we analyzed the number and types of joints.

First, of the 1,669 products surveyed, 637 (38%, Figure 3a) could be considered multi-pose products, according to our criteria. Of the 637 multi-pose products, 358 (21%, Figure 3b) had more than one joint, with number of joints averaging 3.1 (SD: 6.6). Moreover, 176 (11%, Figure 3c) had an arrangement of joints, such that at least one part of the product moved against another moving part. These numbers indicate that a sizable portion of product design may benefit from a system like ours.

Second, only four types of joints were observed in all 637 multi-pose products: hinge joints (587 had them, 92%, e.g. Figure 4a [10]), linear slider joints (157, 25%, e.g. Figure 4b [22]), curved slider joints (12, 2%, e.g. Figure 4c [17]), and ball joints (7, 1%, e.g. Figure 4d [7]); 466 of them (73%, Figure 4e shaded in pink) consisted entirely of hinge joints. These numbers indicate that our proof-of-concept system may initially focus on supporting hinge joints but still address a large proportion of multi-pose products.

System Design

Our system facilitates four main activities (Figure 5): sketching, parting, rigging, and posing. Given that a product concept can frequently change during the initial design stage, we devised our system to permit any activity to be performed in any order and any number of times, through a shared vocabulary of interactions emulating 2D perspective sketching techniques and physical manipulation of an articulated object.

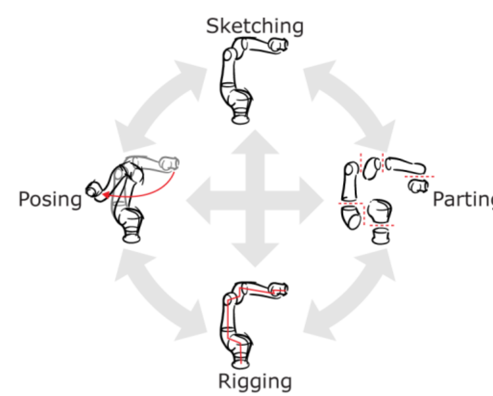

Figure 5: Using our system, the designer performs sketching, parting, rigging, and posing, to ideate and iterate on multi-pose products. These activities can be performed in any order and repeated any number of times.

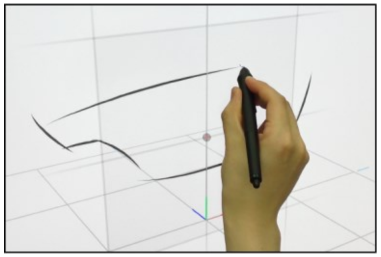

Figure 6: In our system, the designer sets up reference geometries, such as a 3D plane, and then sketches on them.

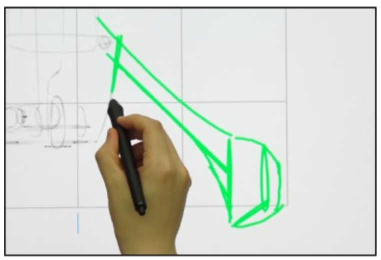

Figure 7: In our system, the designer makes a layer tab, marks curves, and trims them using precise and rough erasers, into separate parts.

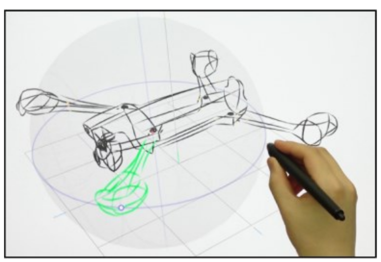

Figure 8: In our system, the designer draws a circular trajectory on a 3D sphere to indicate a rotational motion by a hinge joint.

Sketching

In 2D perspective sketching, the designer often sketches a rough plane or a volume and then sketches curves in relation to it. Similarly, in our system, the designer first sets up a reference geometry and then sketches spatial curves that are projected onto it (Figure 6). Our system supports two types of such reference geometry: a plane [15, 16] and a sphere.

A plane is set up by tapping the pen tip on a grid line or a curve which marks a point in space. Marking one, two, or three points in space creates a spatial plane including the points [15, 16]. Moreover, a sphere is set up by tapping on a grid line or a curve and dragging the pen tip away from the tapped point. Lifting the pen tip up at a point on another grid line or a curve creates a sphere that includes the point on its surface.

Parting

In 2D perspective sketching, the designer often sketches many messy, protruding curves to express a form, and then uses an eraser to trim the edges and define a tidy contour. In addition, the designer often manages distinct portions of a sketch in different layers. Similarly, in our system, the designer marks and trims existing curves and places them into distinct parts through the use of layers (Figure 7).

A part is created by first creating a layer tab and entering it. At first, all existing curves appear unmarked. The designer marks curves by crossing the pen tip over them. The designer trims them with a precise eraser that can unmark portions of curves, or a rough eraser that can unmark entire curves. This process modifies only the information regarding which portions of which curves belong to a particular part; the shapes of the underlying curves remain unmodified.

Rigging

In 2D perspective sketching, the designer sketches a trajectory to indicate a movement, often without specifying the exact physical mechanism of the movement. Similarly, in our system, instead of specifying the position, orientation, and type of joint (e.g. [18]), the designer sketches a trajectory, then the system infers and creates an appropriate joint from the trajectory (Figure 8). Only hinge joints are currently supported.

A hinge joint is created by setting up a reference sphere that includes a point of a parted curve on its surface, and then sketching the desired trajectory of that point on the sphere. The system then creates a hinge joint with an orientation that can most closely approximate that trajectory. If the calculated hinge orientation is sufficiently close to the global X, Y, or Z direction, it is automatically aligned. Using the posing method below, the designer then moves the part against another part along the trajectory to demonstrate that hinge joint's range of motion.

Posing

When physically manipulating an articulated object, people often use one hand to grab onto the part that they wish to hold still, and then use the other hand to take hold of the part that they wish to move [8], often at a point with enough radial distance from the rotational axis to exert torque. Similarly, in our system, the designer uses two hands (while the pen can be tucked [9]) for posing through forward and inverse kinematics. The poses can be stored and restored.

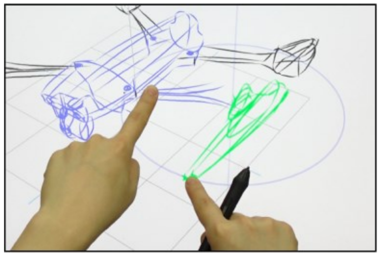

Figure 9: In our system, for forward-kinematics posing, the designer uses one finger touch-and-hold (left hand), and one finger touch-and-drag (right hand).

Figure 10: In our system, for inverse-kinematics posing, the designer uses one finger touch-and-hold (left hand) and a mid-air pinch gesture (right hand).

Forward kinematics posing is performed with two hands' finger touches. The first touch specifies which part is held still, and the second touch specifies the part to be moved (Figure 9). Among several hinge joints connecting all the parts in between the still and moving parts, only the hinge joint that maximizes the radius of rotation is enabled. With the first touch fixed, the second touch-drag rotates the enabled hinge joint.

Likewise, for inverse kinematics posing that enables simultaneous rotation of multiple joints, the designer specifies the still and moving parts with the first and second touches respectively. Then, while holding the first touch, the second hand makes a mid-air pinch gesture. The translation and rotation of the moving part follow those of the pinched hand, and all other parts are posed through inverse kinematics (Figure 10). Clutching is done by repeated pinching and unpinching.

Implementation

The proof-of-concept implementation of our system was written using the Unity game engine. In addition to Unity's native 3D graphics and rigging capabilities, BioIK, an inverse kinematics solver for Unity [20, 21], was used. A Leap Motion hand tracking sensor was used for spatial hand tracking. Our system ran on pen- and multi-touch-capable digital tablets including the Wacom Cintiq 24HD Touch and MobileStudio Pro 16.

Pilot Test

To assess the usefulness of our system in professional practice, we conducted a pilot test, consisting of two informal workshops using the above implementation. Two professional industrial designers, with 9 (P1) and 6 (P2) years of work experience, respectively, used our system (Figure 11) to sketch multi-pose product concepts (Figure 12, 13) meeting the criteria outlined in Survey section. Two key findings from observations and interviews are:

Helping the initial stage of multi-pose product design
In comparison to traditional 2D perspective sketching, designers noted that *"this tool is useful because it saves you from having to draw multiple sketches (P1)"* of the same form, in different poses and perspectives, especially when changes are made to the form.

Whereas designers previously had to make bothersome and time-consuming jumps between dedicated 3D tools they used for modeling (Autodesk Alias) and for rigging and animating (Autodesk Maya), which are more suited to later stages of design, they appreciated the ability to *"do the sketch, pose the sketch, and then sketch again in the same tool (P1)"* during the early stage of design, with interactions that are *"intuitive and natural (P1)."*

Designers also noted that our system can accelerate the initial stage of designing a multi-pose product by allowing them to *"quickly test if an idea would work earlier on in the process, even before any modeling (P1)"* and *"express an idea of a shifting form in a way that can be easily shared with others (P1)."*

Form and pose inspiring one another
We observed designers improving the form of the product based on the pose (e.g., adjusting the length of the frame of a foldable e-bike so that both the front and back wheels make contact with the ground when the frame is folded, P1), as well as improving the pose of the product based on the form (e.g., adjusting the position of the hinge joint connecting the roof of a self-driving vehicle to its body so that it smoothly slides along the curve of the body when it opens, P1).

Figure 11: Two professional product designers (a) with 9 and (b) 6 years of respective work experience used our proof-of-concept implementation to sketch multi-pose products. Their working procedures were observed, and they were interviewed later for comments.

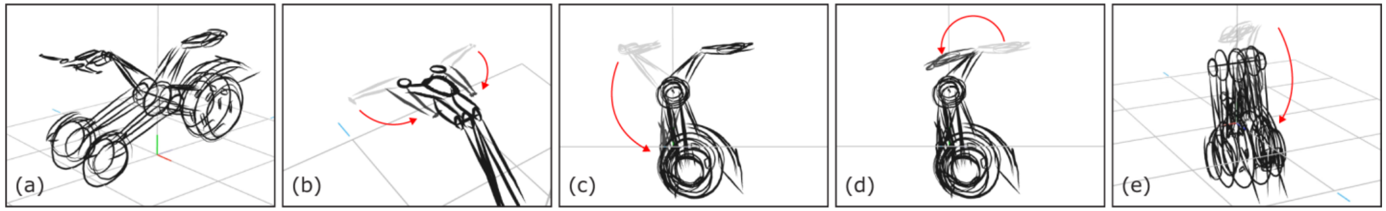

Figure 12: (a) A 3D sketch of a concept foldable e-bike produced using our system. Sequentially, (b) the bike handle, (c) the front of the bike, and (d) the back of the bike are folded into (e) the portable form.

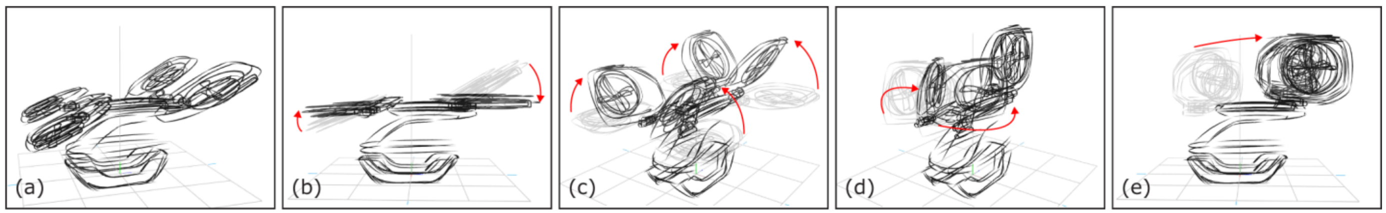

Figure 13: (a) A 3D sketch of a concept flying-car produced with our system. (b-e) The four thrusters perform a series of maneuvers to become fully folded after landing.

Regarding how using our system impacted their creative thought process, designers noted that they were constantly experimenting: *"what would be a good pose for a part that is shaped like this? (P2),"* and *"what would be a good shape for a part that can pose like this? (P2)"* To us, these remarks indicated that, by using our system, designers were able to ideate and iterate on both the form and pose of a product in an interconnected manner.

Conclusion & Future Work

In this study, we proposed a 3D sketching system for multi-pose products, with at least one rigid moving part, the movement of which is structural and nondisruptive. Through a survey analyzing 1,669 product concepts, we found that multi-pose products are prevalent and that many of them have more than one moving part, and each part often moves against another moving part. We designed interactions emulating traditional 2D perspective sketching practices and physical manipulation of articulated objects, in a way that enables designers to flexibly sketch, part, rig and pose sketches. A pilot study with professional product designers showed that our system can help designers quickly try many different form and movement ideas in 3D during the early stage of design. Areas of future work include supporting joint types other than the hinge joint and enabling designers to create presentable videos that smoothly transition from one discrete pose to another.

Acknowledgment

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