

Basic Elements for Curved Origami Design

J. Mitani

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Abstract

Mathematics on the geometry of origami has been actively studied, and curved folding is one of hot topics in recent years. Since folding a curve has a high degree of freedom, various shapes can be formed from a single curve scored on a flatten sheet, depending on its folding angle and the shape of the curve in three dimensions defined by its curvature and torsion[1]. For that reason, it is still difficult to use computer for intuitive design of curved origami. On the other hand, the creation of origami sculptures with curves, has been done since long before, as represented by Huffman's work[2]. Many are thought to be designed without using software, but based on human experience and intuition, sometimes with knowledge of mathematics. Although there are publicly available CAD tools or simulator today for curved origami such as ORI-REVO and ORI-REF, its variations are strongly limited by the algorithms of design tools. For example, the shape designed by ORI-REVO is restricted to have rotational symmetry. This seems to be the reason why most of the artworks of curved origami looked designed without using dedicated CAD tools even today.

In our research, we investigated existing curved origami pieces, and extracted commonly observed basic structures or techniques. Table 1 shows some elements we classified (because of space limitation, only a part of elements are shown). We would like to propose them as basics for curved origami as sink-fold, petal-fold and the water bomb base are known for basics of flat-fold origami. By appropriately combining them, it becomes possible to create curved origami rich in expressiveness without using advanced calculations nor extensive experience. Figure 1 shows examples that we created with this approach without using CAD tools (just with a 2D drawing tool). We further hope that the list of basic elements could give valuable knowledge for developing CAD tools for curved origami in future.

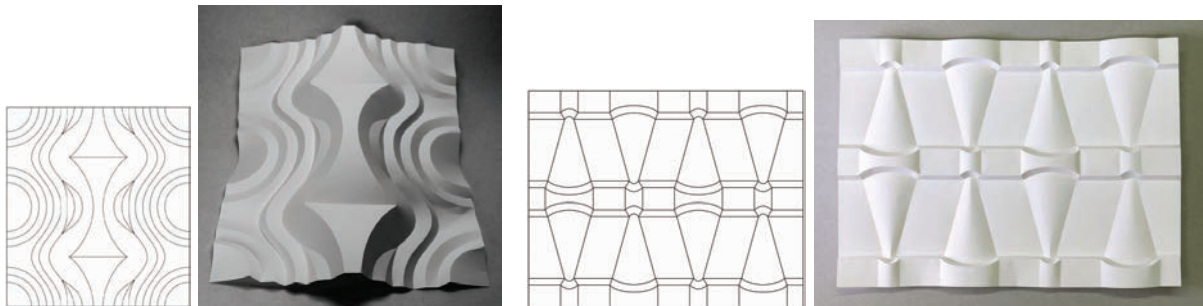
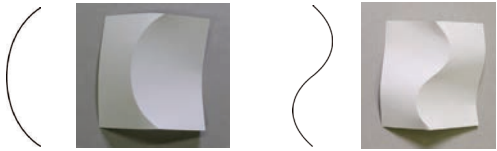


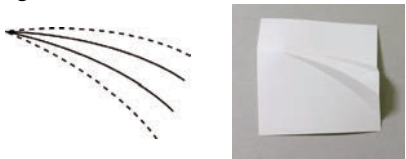
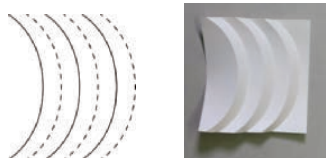
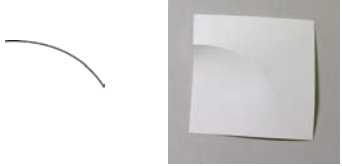
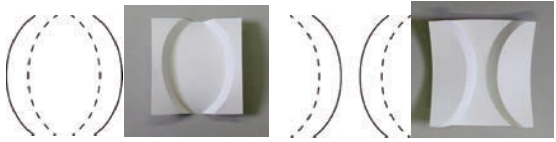
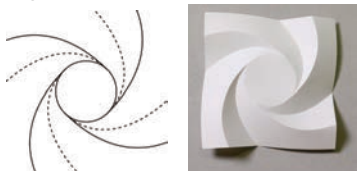
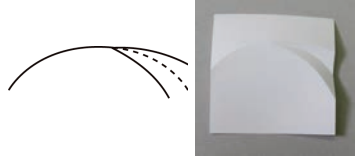
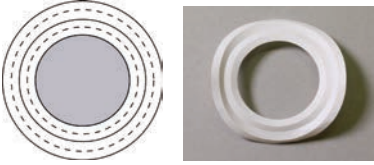


Figure 1. Examples of curved origami designed by combining basic elements.

Table 1. Crease patterns and folded states (photos) of basic elements of curved origami.

<p>(1) Single curve</p>  <p>The simplest curved fold. Two developable surface patches touch each other across the curved crease. The shape changes according to the form of the curve in three dimensional space.</p>	<p>(6) Partial cone</p>  <p>A part of circle and a linesegment whose end point is at the center of the circle makes a partial cone.</p>
<p>(2) Curved step</p>  <p>A pair of the almost same curves with different m/v parity makes a curved step.</p>	<p>(7) Flange</p>  <p>Valley-Mountain-Mountain-Valley curves (and vice versa) makes a flange and makes the surface round.</p>
<p>(3) Repetition</p>  <p>Repetition of the almost same curves with alternative m/v parity makes curved steps or pleats.</p>	<p>(8) Ending in the middle</p>  <p>A curve ending in the middle makes smooth transition between concave and convex surfaces.</p>
<p>(4) Mirroring</p>  <p>Mirroring a step or a simple structures makes a symmetrical form.</p>	<p>(9) Winding</p>  <p>Foldings arranged in a spiral form around a circle makes a winding up structure.</p>
<p>(5) Sink fold</p>  <p>The sink-fold, a technique commonly used for flat-fold origami, is also applicable for a curved fold.</p>	<p>(10) Circles</p>  <p>Although it is difficult to combine with other elements, concentric fold lines create a unique form.</p>

Reference

- [1] D. Fuchs, S. Tabachnikov, More on Paperfolding, *The American Mathematical Monthly*, Vol. 106, No.1, pp. 27-35, 1999.
- [2] M. Wertheim, Cones, curves, shells, towers: He made paper jump to life. *The New York Times*, June 22, 2004.