

Degree of Freedom Reduction for Rigid Origami Patterns through Vertex Splitting Technique

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Abstract

Six-crease rigid origami patterns, such as the diamond pattern and the waterbomb pattern, are able to be deployed to variable configurations, and therefore have great potential in engineering applications. As each vertex of such origami pattern can be considered as a spherical $6R$ linkage with three degree of freedom (DOF), the entire pattern is a multi-DOF system, which makes it difficult to fully control the motion of such patterns. A thickness-accommodation method through offsetting revolute joints has been proposed to reduce the DOF of those patterns, at the cost of losing the flat surface profiles of thick panels. Here we propose a vertex splitting technique to reduce the DOF of such multi-DOF origami patterns. By this means, the new patterns retain the flat surface profiles and the kinematic property of the original one.

First of all, on a plane-symmetric single-vertex six-crease pattern (Figure 1a), the single-vertex is split into multiple vertexes through three ways, i.e., towards the direction parallel to the symmetric creases, towards the direction perpendicular to the symmetric creases, and towards both. Three new patterns (Figure 1b-d) are obtained correspondingly. To judge the DOF and compatible conditions of the patterns, kinematic analyses are carried out based on Denavit and Hartenberg (D-H) notation. The results indicate that two patterns (Figure 1b, d) have 1-DOF and reserve the symmetric folding behaviour of the original pattern.

Secondly, the vertex splitting technique is applied to a multi-vertex diamond pattern, resulting in three types of 1-DOF patterns including a flat-foldable one and two non-flat-foldable ones. Kinematic analyses of the three patterns show that all of them reserve the symmetric folding behaviour of the diamond pattern. Meanwhile, the condition for a vertex splitting origami pattern to be 1-DOF is also obtained, i.e., every multi-DOF spherical linkage is controlled by the connected spherical $4R$ linkages and the origami pattern satisfies compatible conditions.

To summarize, the vertex splitting technique can effectively reduce the DOF of multi-DOF origami patterns, while the flat surface profiles and the kinematic property of the original pattern are still retained. This approach would significantly facilitate engineering applications of multi-DOF origami patterns.

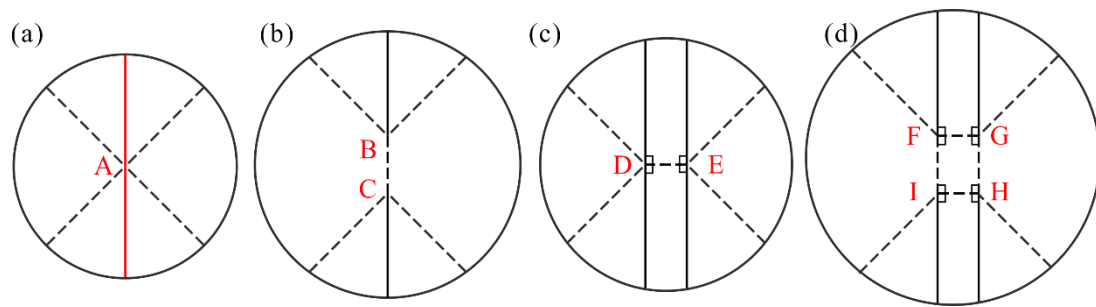


Figure 1: A plane-symmetric single-vertex six-crease pattern and its vertex splitting patterns.

(a) The original single-vertex pattern; three vertex splitting patterns derived from three splitting ways, (b) towards the direction parallel to the symmetric creases, (c) toward the direction perpendicular to the symmetric creases and (d) towards both. Here the red creases are the symmetric creases.