Origami Structures:
Kinematic Design and Engineering Application

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Abstract

Origami is a traditional art of paper folding. The origami-inspired technologies are efficient in folding large scale structures into smaller one. This character attracts scientists from different fields including artists, mathematicians, and engineers. The major interest of the scientists is to design and analyse origami patterns, while engineers are more interested in exploring the applications of the origami structures. Rigid origami is a special family of origami. In its folding process, the paper surrounds with the creases and the other areas do not stretch or bend. Since most of the surfaces, e.g., satellite antenna reflectors and solar arrays, and sheet materials, are used in engineering applications The rigid origami allows the patterns to be readily utilised for packaging large spatial structures, or being manufactured from modern materials such as plastic, metal, or carbon-fibre sheets.Therefore, this work focuses on the design and analysis of rigid origami and exploration of their engineering applications.

Three typical rigid origami patterns have been studied with the kinematic tools. Firstly, through the analysis on the rigidity of the crease patterns with multiple vertices each with four crease lines, a frame work has been setup not only to analyse the rigidity of the existing pattern, but also to find the new patterns and provide new solutions to the deformable polygons in discrete differential geometry. Secondly, the foldable tubular structures with rigid origami pattern have been found. Thirdly, the square-twist pattern has been discussed with the effect of mountain and valley crease assignment.

Meanwhile, the engineering applications of the proposed rigid origami structures have been carried out. The square-twist pattern can be tessellated into a planar large scale deployable structure with largest deployable ratio close to 9 for the aerospace solar arrays. It also can be stacked into multi-layer structures, called metamaterial, which exhibits negative Poisson's ratio with the potential to be used as smart fiber materials for various large load conditions. The foldable tubular structures have been applied as emergency shelters, which could be developed for space masts and other structures requesting large deployable ratio in the axis direction. When the structures are made from continuous sheet, the tubular structures have been used as energy absorbing devices in automobile industry, which show excellent mechanical behaviour under the axial loading. Furthermore, combining the rigid origami structures and compliant concepts, expandable medical devices have been developed for implanted devices and miniaturedoperation tools in minimally invasive surgery. Currently, expandable tubes in either axial direction or radius one are designed for Natural Orifice Transluminal Endoscopic Surgery to provide the requested flexibility and stiffness of endoscopic structures.

Keywords: rigid origami; kinematics; compliant mechanism; deployable origami structures; expandable medical devices.