

Crawling Cylindrical Origami Robot Driven by Single Actuator

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Abstract

Cylindrical folding is a structure that greatly transforms its length without changing the outer diameter, which is proposed for a vibration isolator or space deployment structure by using the bistable/inflatable property (see Figure 1). We use this cylindrical folding as a multipurpose exoskeleton of the robot. Up to now, conventional cylindrical robots such as serpentine and caterpillar ones were driven by the legs and wheels attached to them. However, the number of such legs and wheels is often numerous, which leads to the increasing number of actuators and more complicated control. On the contrary, the proposed robot only controls its body length; yet such a simple control realizes its friction and stride. It realizes multiple locomotion modes.

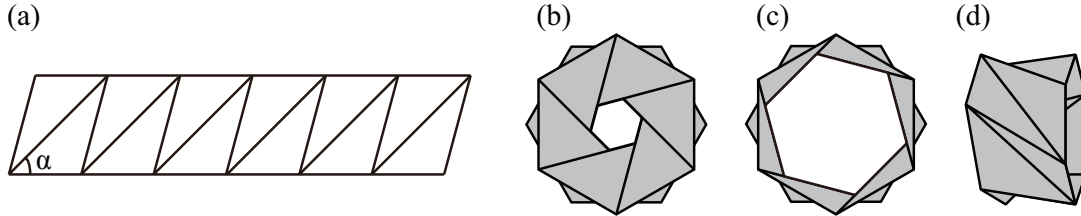


Figure 1: (a) The net of cylindrical folding. (b) The top view of contracted cylindrical folding. (c) The top view of elongated cylindrical folding. (d) The side view of expanded cylindrical folding ($\alpha = 45^\circ$). Folded state and elongated state are stable.

Cylindrical folds show a bistable behavior, so when the applied force exceeds a certain value, it folds in a twist at a stroke. Also, the order of shrinkage can be adjusted, since the stiffness of each cylindrical fold can be adjusted by laser cutting/graving with different power or by changing sheet materials. When cylindrical segments with such different stiffnesses are connected, they contract/elongate from the segment with the lowest stiffness in sequence (see Figure 2). So, when we deploy the segments with higher stiffness in the end of the robot and the segments with lower stiffness in the center, cylindrical robot contracts/elongates from the central segments in order. We call this discrepancy between contraction/elongation hysteresis.

The cylindrical folding not also shrinks, but also twists. This twisting property makes possible the control of its friction to the ground. Let us consider a robot in which the front half is a cylindrical folding in one direction (“R” in Figure 2) and the rear half is a cylindrical folding

in the other direction (“L” in Figure 2). According to the hysteresis property described above, when the robot contracts/elongates, the innermost segments firstly twists. Due to this property, the internal twisted angles are different between contracted/elongated state.

Therefore, by applying materials with different friction to each edge of the hexagon, we can control the friction of the robot to the ground. This robot can move forward (right in Figure 2) by making the friction of the front half higher in contraction, and by making the friction of the rear half higher in elongation respectively.

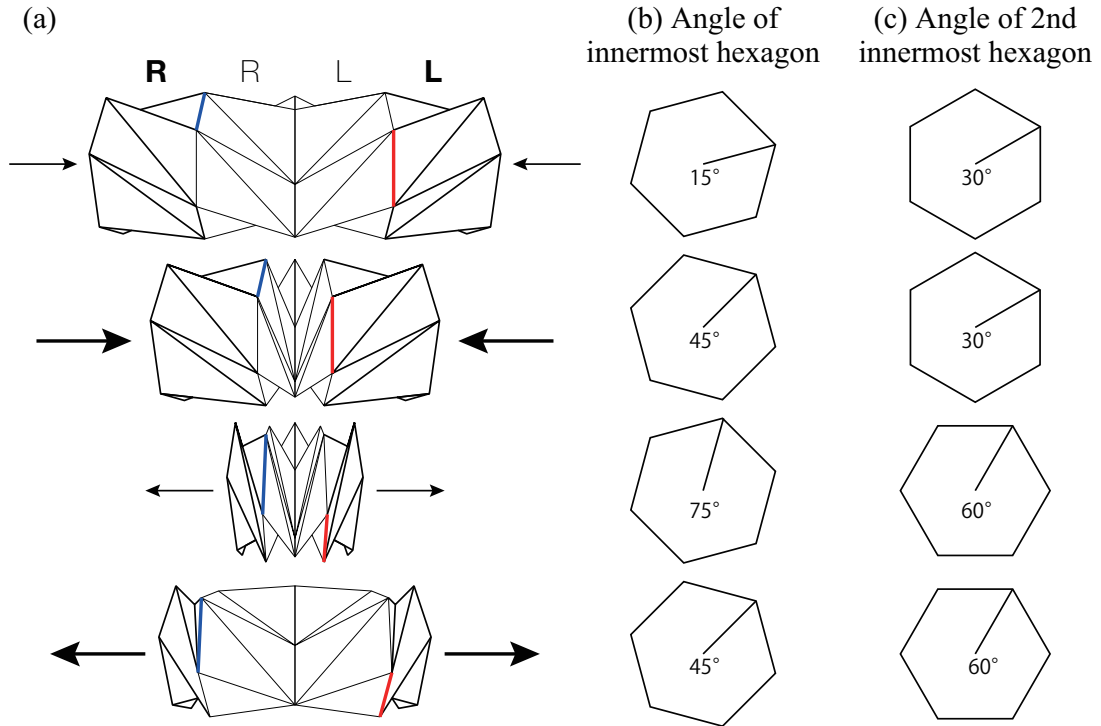


Figure 2: Hysteresis property of a cylindrical robot. (a) R and L mean the twisting directions, right and left. The line width of folding means each stiffness of folding. Vector width means contraction/elongation pressure. In contraction phase, inner low stiffness segments are folded first. In elongation phase, inner low stiffness segments are elongated first too. By controlling the iteration of contraction/elongation, this robot can locomote in the right direction using friction. The angle of the innermost (b) and the second innermost hexagon (c) are shown. The angle of the second innermost hexagon is decided by hysteresis property of the robot.

We also make use of hysteresis to realize different strides. For example, when the robot cannot completely elongate in a narrow place, it only drives the innermost segments by controlling the elongation. As another example, when the robot wants to locomote on a stable ground, it transforms its length as much as possible, while on an unstable ground where it needs more friction force, it only drives the innermost segments to increase friction to the ground.

In this way, we realize a cylindrical robot that can change its body length, friction, and stride with only single actuator.

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