Supplementary Material

Towards Mechanically Intelligent Reconfiguration via Origami Bifurcations

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Contents

1 Videos of Segment Bifurcations and Crawling-like Behaviours

A supplementary video is available at: `https://youtu.be/7DZKrLI19DM`. The video first illustrates the bifurcation behaviour of a single origami segment. Crawling-like behaviours of actuated segments are also demonstrated, which are then fine-tuned to crawl forward.

2 Joint-Level Fatigue Experiment Setup

The specimen for joint fatigue test is illustrated in Fig. S1. It is a Sarrus linkage [1], which converts rotational joint motion into a linear stroke and allows testing on a universal machine [2]. Rigid PLA plates serve as origami facets and glass-fibre tapes form the rotational joints, matching the robot prototype. Geometric parameters are illustrated in Fig. S1. Tests were performed on an Instron 5980 with a displacement amplitude of 20 mm, which is within the maximum displacement of 30 mm between upper and lower plates as set by the linkage. The upper plate moves at 1 mm/s for 1,000 cycles. A time-lapse of the cyclic motion is available at: `https://youtu.be/b5pk5_mPoTA`, which is played at 25X real time. After 1,000 cycles, the specimen was inspected for damage.

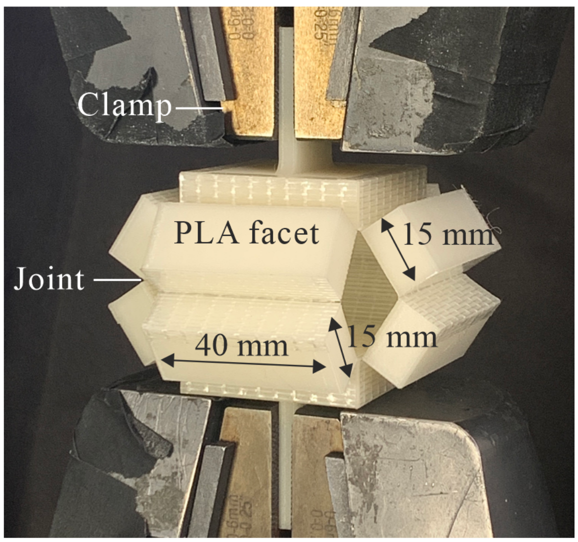

Figure S1: Experimental setup of joint-level fatigue test on an Instron universal machine.

References

[1] K. J. Waldron, G. L. Kinzel, and S. K. Agrawal, *Kinematics, dynamics, and design of machinery*. John Wiley & Sons, 2016.

[2] T. Koetsier and M. Ceccarelli, *Explorations in the History of Machines and Mechanisms: Proceedings of HMM2012*. Springer Science & Business Media, 2012, vol. 15.

3 Calculation of Marker Distance

The distance $d_{i,j}$ between marker i and marker j is given as follows.

For the single segment in Fig. 7(a),

$$d_{2,\,7}^2 = 2(\frac{l^2}{3} + d_0^2)(1 + \cos(\varphi_{12} + 2\arctan\frac{\sqrt{3}d_0}{l})) \tag{1}$$

$$d_{3,\,4}^2 = \frac{l^2}{3} + 2(h+d_0)^2 - 2\sqrt{(h+d_0)^2 + \frac{d^2}{12}}(h+d_0)\cos(\varphi_{12} + \theta_1) \tag{2}$$

$$d_{4,\,5}^2 = \frac{l^2}{3} + 2d_0^2 + 2\sqrt{(\frac{l^2}{16} + s_0^2)(\frac{l^2}{12} + d_0^2)}\cos(\varphi_{12} + \theta_2) \tag{3}$$

$$d_{5,\,10}^2 = 2((h+d_0)^2 + \frac{3l^2}{16})(1 - \cos(\varphi_{12} + 2\theta_3)) \tag{4}$$

$$d_{8,\,9} = d_{3,\,4},\; d_{9,\,10} = d_{4,\,5} \tag{5}$$

where

$$\theta_1 = \arctan\frac{\sqrt{3}l}{6h + 6d_0} \tag{6}$$

$$\theta_2 = \arctan\frac{4\sqrt{3}d_0}{3l} + \arctan\frac{2\sqrt{3}d_0}{l} \tag{7}$$

$$\theta_3 = \arctan\sqrt{\frac{\sqrt{3}l}{4h + 4d_0}} \tag{8}$$

For the double segments in Fig. 7(b),

$$d_{2,\,7}^2 = 2(\frac{l^2}{3} + d_0^2)(1 + \cos(\varphi_{12} + 2\arctan\frac{\sqrt{3}d_0}{l})) \tag{9}$$

$$d_{3,\,4}^2 = 2(\frac{l^2}{12} + (h+d_0)^2)(1 - \cos(\varphi_{12} + 2\arctan\frac{\sqrt{3}l}{6h + 6d_0})) \tag{10}$$

$$d_{4,\,5}^2 = 2(\frac{l^2}{12} + d_0^2)(1 + \cos(\varphi_{12} + 2\arctan\frac{2\sqrt{3}d_0}{l})) \tag{11}$$

$$d_{2,\,15} = \frac{2((2h+d_0)\sin\frac{\varphi_1}{2} + \frac{\sqrt{3}}{3}l\cos\frac{\varphi_1}{2})}{\sqrt{1 + \cos^2\frac{\varphi_1}{2}}} \tag{12}$$

$$d_{8,\,9} = d_{5,\,10} = d_{3,\,4},\; d_{3,\,8} = d_{9,\,10} = d_{4,\,5} \tag{13}$$

For the double segments in Fig. 7(c),

$$d_{7,\,10}^2 = 2(\frac{l^2}{3} + d_0^2)(1 + \cos(\varphi_{12} + 2\arctan\frac{\sqrt{3}d_0}{l})) \tag{14}$$

$$d_{1,2}^2 = (\frac{3d_0}{2} - \frac{l}{4})^2 + (\frac{h}{2}\sin\delta_1 + (\frac{\sqrt{3}l}{4} + d_0)\cos\delta_1 + \frac{\sqrt{3}l}{2} - d_0)^2 + (\frac{h}{2}\cos\delta_1 + (\frac{\sqrt{3}l}{4} + d_0)\sin\delta_1 - d_0)^2 \quad (15)$$

$$d_{2,3}^2 = (d_0 + \frac{h}{2}\sin\delta_2 + \frac{\sqrt{3}l}{4}\cos\delta_2)^2 + (\frac{l}{4} + \frac{\sqrt{3}d_0}{6})^2 + (h - d_0 - \frac{h}{2}\cos\delta_2 + \frac{\sqrt{3}l}{4}\sin\delta_2)^2 \quad (16)$$

$$d_{4,5} = d_{1,2},\ d_{3,4} = d_{2,3} \quad (17)$$

where

$$\tan\frac{\delta_1}{2} = \frac{\sin\frac{\delta_2}{2}}{2\cos\frac{\delta_2}{2} - \sqrt{3}},\ \tan\frac{\delta_2}{2} = \frac{\sin\frac{\varphi_{12}}{2}}{2\cos\frac{\varphi_{12}}{2} - \sqrt{3}} \quad (18)$$