Rapid Transformation of Origami Devices

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Abstract

Origami, the Japanese art of paper folding, has numerous applications in the field of engineering, ranging from satellite panels to bullet proof vests. Though origami engineering is a promising approach to transforming machines, the fundamental dynamics of origami systems are not well understood. We sought to study the behavior of a single carbon fiber Miura fold, ultimately creating two models. The first represented the relationship between base torque and vertex displacement for different backlash levels; the second analyzed the kinetic and potential energies of the fold in order to predict when it will transform. Our primary objective, however, was to design an origami device with planned choreography. The Miura-inspired mechanism utilized a network of six vertices, two different levels of backlash, and added weights. This allowed for a number of complex configurations, which we controlled using a spring-powered setup.

Background

Origami machines can be used to rapidly transform geometries from a 2-dimensional state to a 3-dimensional state. In the past year, Liu *et al.* worked on developing a model for the amount of torque needed to transform a single polystyrene Miura fold. The Miura fold pattern is a tessellation of identical vertices, each with four creases. Two of these, the spinal creases, are collinear when flat and the other two, the peripheral creases, are symmetric across the spine with a peripheral angle α between the spinal and peripheral creases. An ideal Miura fold has faces that are completely rigid, so there are only two configurations: parallel and antiparallel. Each configuration has one degree of freedom.

Torque was modeled versus the displacement of the Miura vertex, determining that the starting angle of the base affects the vertex behavior. Therefore, it requires greater torque to undergo displacement with a larger starting angle. From that model, Liu *et al.* calculated the potential energy of the system by integrating along the torque curve. They determined that when the kinetic energy is greater than the potential, the fold will push through into the other configuration.

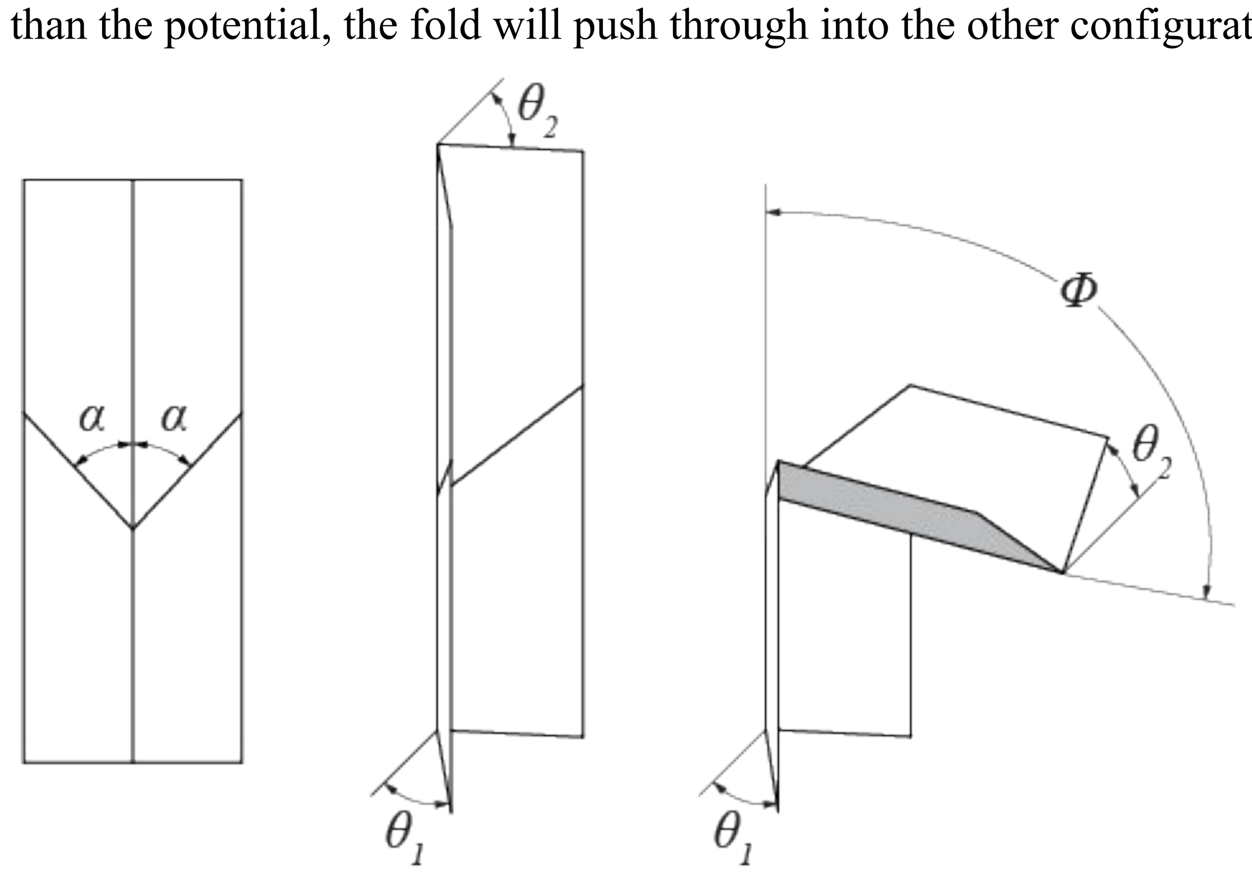
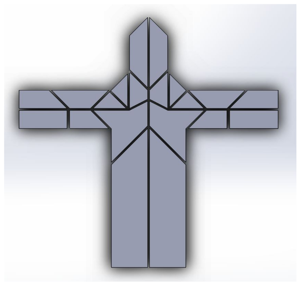


Figure 1: *Left to right: flat Miura fold, parallel configuration, antiparallel configuration.*

Experimental Methods

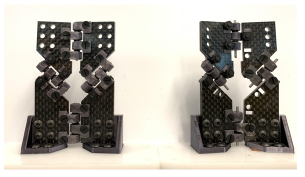
Sample Design:

- Create Miura-inspired mechanism with complex configurations
- Consider angle and dimension of folds to predict the motions



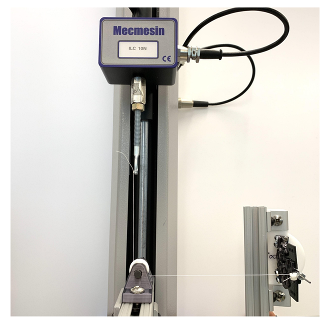
Sample Fabrication:

- Assemble model with six vertices using Prusa 3D printed hinges and CO_2 laser cut acrylic plates
- Assemble model with single vertex using Prusa 3D printed hinges and U4 laser cut carbon fiber plates
- Vary backlash for certain folds



Characterization of Pseudo-Joint Stiffness:

- Test stiffness of single carbon fiber Miura fold from four different starting positions
- Create model of relationship between base torque and vertex displacement based on results

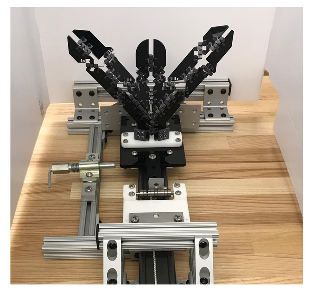


Characterization of Pseudo-Joint Dynamics:

- Use motion tracking technology to study how ratio of kinetic to potential energy can predict transformation in a single carbon fiber Miura fold

Sample Testing:

- Manually apply force to sled to achieve desired configurations of origami device
- Setup powered by three steel extension springs



Results

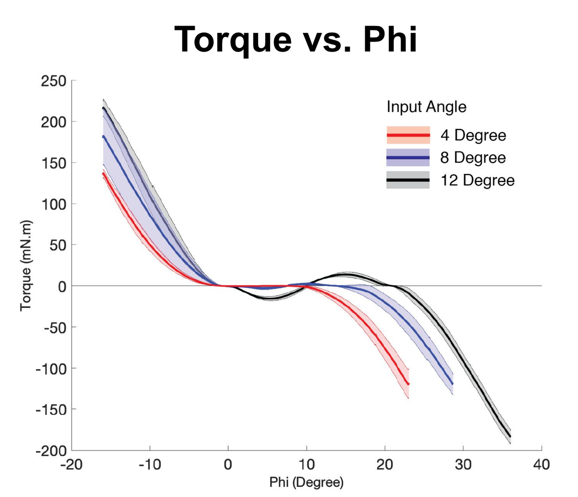


Figure 2: *Left: torque vs. phi (joint angle) for different base angles of a Miura fold*

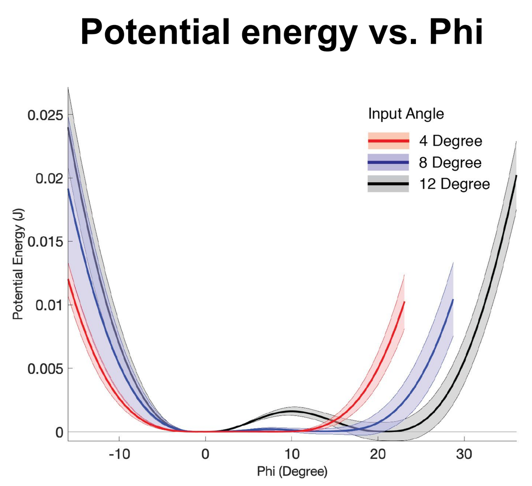


Figure 3: *Left: potential energy vs. phi (joint angle) for different base angles of a Miura fold*

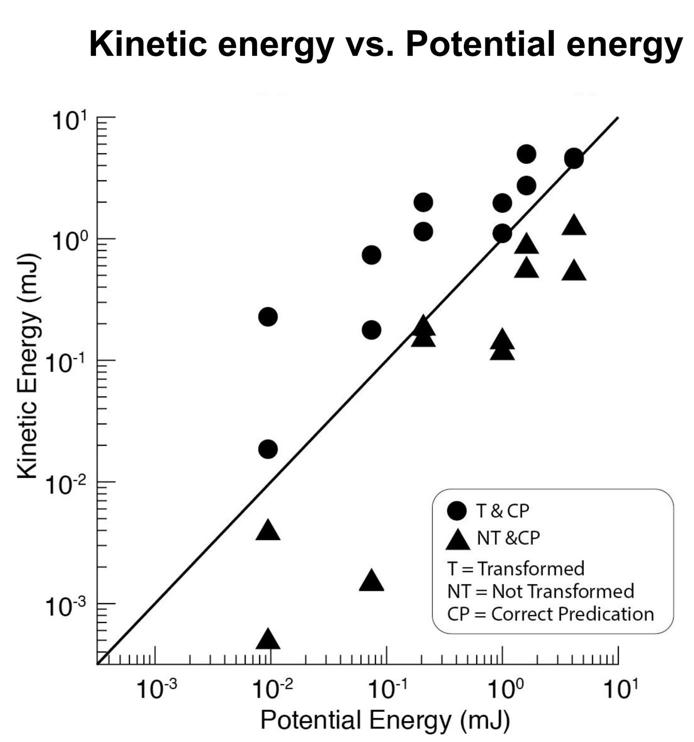
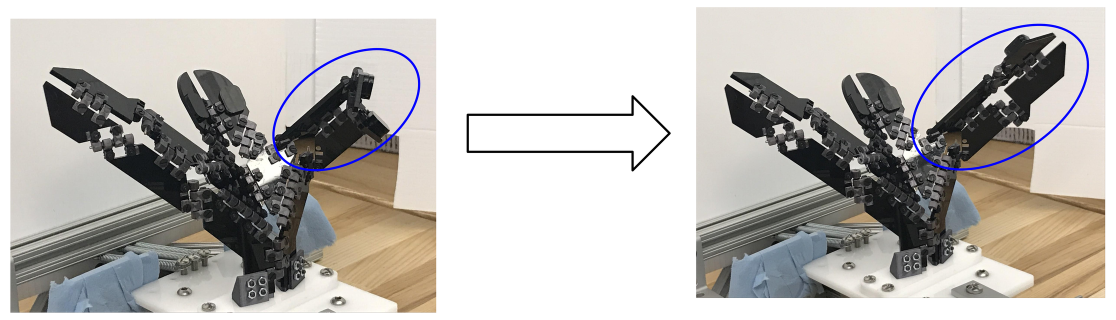


Figure 4: *Above: predictive model for transformation of single Miura fold based on potential and kinetic energy*

Demo Implementation

We mounted our origami device to a sliding plate and manually applied force using a spring-powered setup. Ultimately, we were able to achieve three distinct configurations by modifying several parameters: displacement, starting position, and base direction. When the parameters were kept constant, the device transformed predictably.

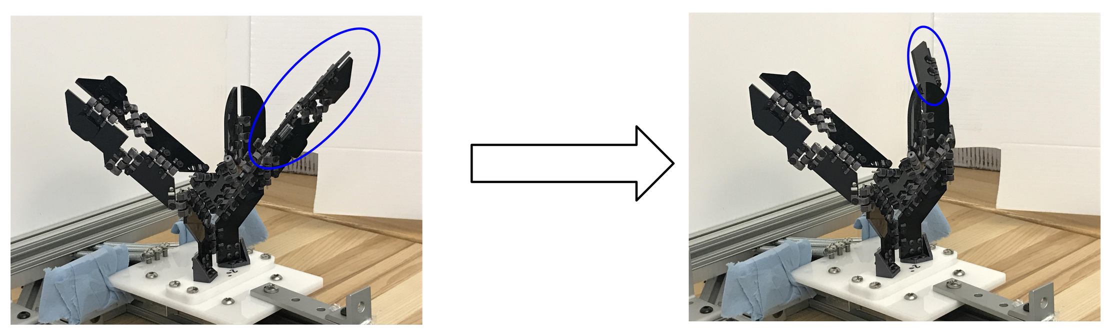
Configuration 1 - Small single arm motion



10-11-00 → 10-10-00

Forward base
20° angle
Stopper distance: 5 cm

Configuration 2 - Large single arm motion



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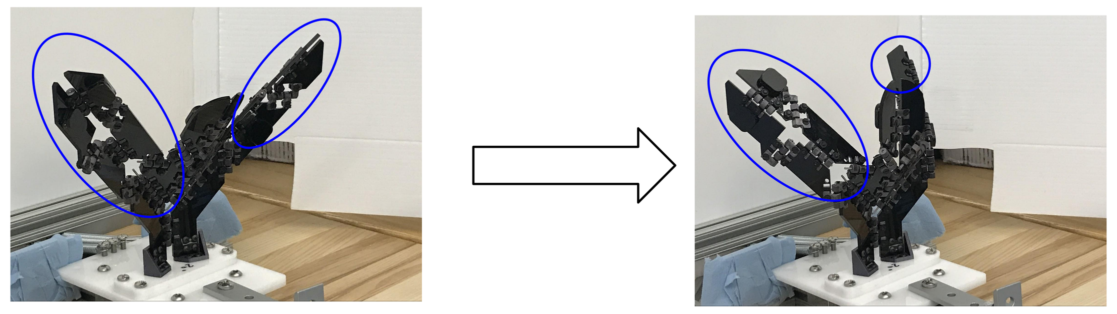
Reverse base
20° angle
Stopper distance: 8 cm

Configuration 3 - Large double arm motion



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Reverse base
20° angle
Stopper distance: 6 cm

Conclusion and Future Steps

Origami can be applied to create predicted transformations in single Miura fold samples. We can use Miura folds to fabricate a structure capable of making essentially any desired transformation that we may have. Moving forward, the technology can be built off of to function for a greater number of vertices (i.e. our model) and expanded to consider a larger range for certain parameters, such as input angle and stiffness level. The fabrication process will be improved to include parts more uniformly created than those made by the 3D printers we have access to today. Furthermore, dynamic testing will be automated to increase consistency and precision. All of these changes enable folding technology to perform increasingly complex and intricate transformations. Machines that employ this advanced technology to rapidly achieve desired transformations could, ultimately, have infinite uses.

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