Developing a Simulation for Re-Programmable Magnetically Self-Folding Origami Structures

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Abstract

Self-folding structures have immense potential in many forms of cutting-edge scientific developments. From **space travel** to **biotechnology**, the ability to place a small, unassembled in a desired location and fold it has huge potential applications in many fields. While other methods of self-folding, for example, through heat can work, those methods are inflexible and don't allow for reconfigurable structures. Continuing on a development out of UPenn's Sung Lab, this project aims to develop a simulation of a new, **magnetically actuated** form of self-folding structures that we've dubbed **programmable matter**.

Introduction

By taking a magnetic material and cutting creases into it, we can create **foldable magnetic structures**, which can be programmed to have a particular polarity pixel-by-pixel. By combining certain crease patterns with certain configurations of polarities, we can create sheets of magnetic material that will **automatically fold into a given shape** when an external magnetic field is applied. This has far-ranging applications in various fields, with the possibility of bringing unassembled magnetic structures into space and assembling them using strong magnetic fields, or inserting structures into the human body and actuating them using an external magnetic field, which **removes the need for bulky and complex electronics inside the human body**. However, the manufacturing and testing process for these magnetic structures is relatively slow, which limits the speed at which further research can be done. In response, this project aims to develop a **novel simulation**, which will allow the folding behavior of these structures to be simulated rather than physically tested.

Methodology

Over the course of this project, various approaches were considered.

- Use an existing physics engine
  - Pros:
    - Cross-compatible between machines
    - Widely tested and debugged
  - Cons:
    - Largely in C++, while we preferred to use Python
    - Poor at simulating interconnected soft bodies
    - Portability and maintenance issues with libraries
  - Ultimately, existing engines were not adequate for this application
- Use the MERLIN2 software[1]
  - Developed by researchers at Georgia Tech
  - Allows finite element analysis of origami structures
  - Pros:
    - Used frequently in Sung Lab
    - Detailed documentation through academic writing
  - Cons:
    - Written in Matlab

Ultimately, the **MERLIN2 software** was the most effective for this application. This also provided the opportunity to create a **comprehensive** and **well-documented Python port** of the software which could be made **open-source**.

Results

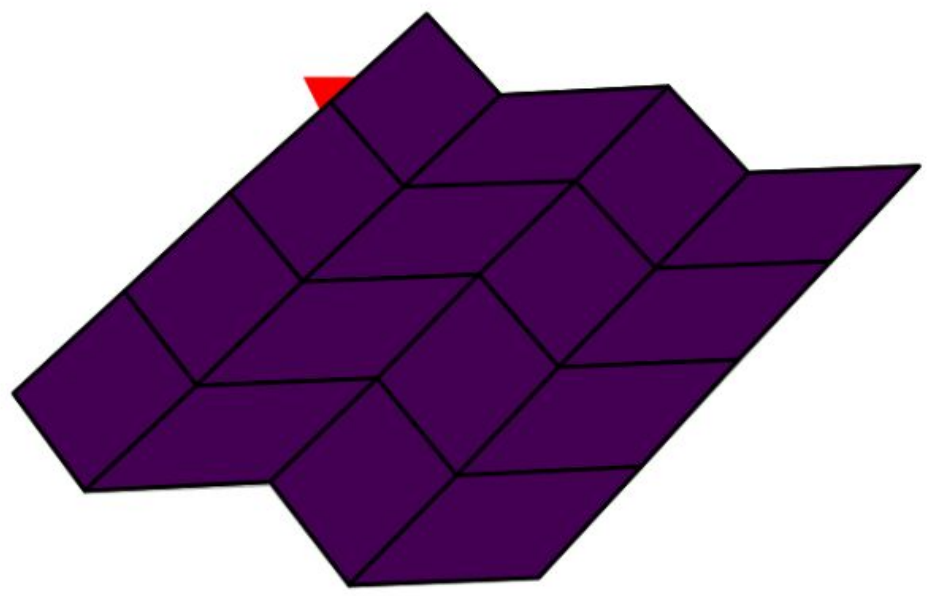

Fig. 1 An unfolded version of the Miura origami pattern loaded into our port of the MERLIN2 software

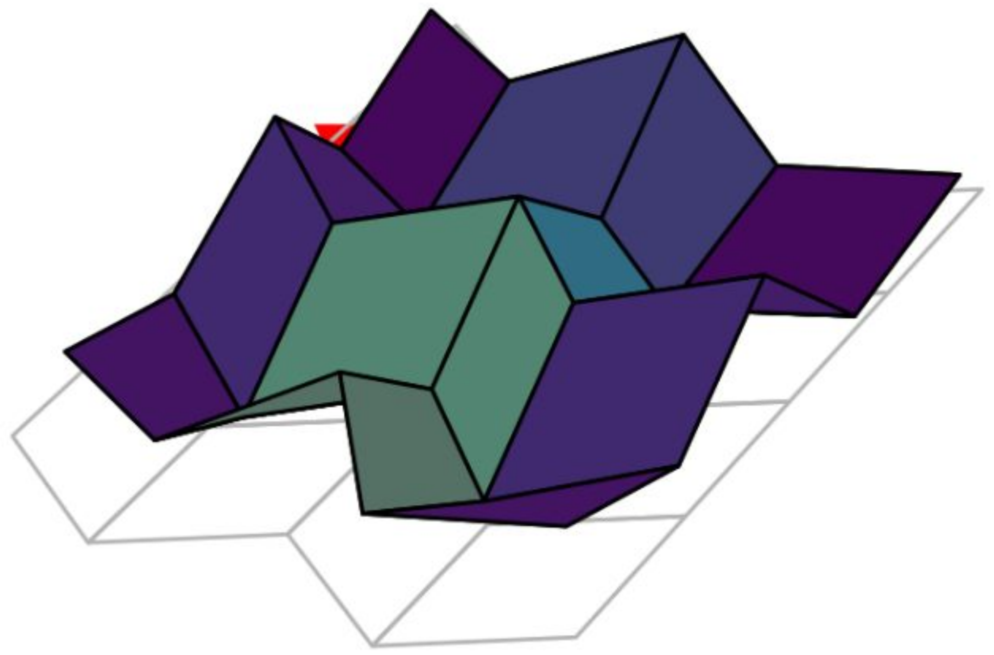

Fig. 2 The folded version of the same pattern, simulated using MERLIN2

Conclusion

While the project isn't finished yet, the Python port of MERLIN2 is complete and the magnetic simulation is well underway. We have also considered **future work** based on this software. One consideration is the addition of **self-collisions** into MERLIN2, which would make the simulation more accurate. Another consideration is the use of this software to train a **generative neural network** to generate fold patterns based on a desired final shape, taking advantage of recent advances in generative AI to effectively enable us to create any given structure with this technique.

Future work could also be put into the continued development of the MERLIN2 Python port, which can be made more comprehensive and better-documented in order to be accessible to as many people as possible. The development of open-source software, though not the original purpose of this project, is extremely important in making the study of origami structures more accessible.

Acknowledgements

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1. Liu, K., & Paulino, G. H. (2018). Highly efficient nonlinear structural analysis of origami assemblages using the MERLIN2 software. Origami, 7, 1167-1182.