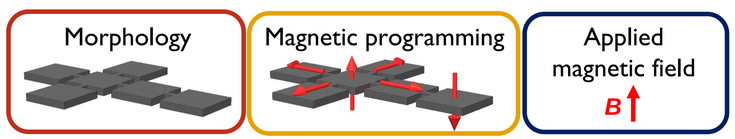
Data-driven inverse design optimization of magnetically programmed soft structures

Alp C. Karacakol[1,2], Yunus Alapan[1], Metin Sitti[1,3,4]

[1]Physical Intelligence Department, Max Planck Institute, [2]Mechanical Engineering Department, Carnegie Mellon University,
[3]School of Medicine and School of Engineering, Koç University, [4]Institute for Biomedical Engineering, ETH Zurich

Introduction

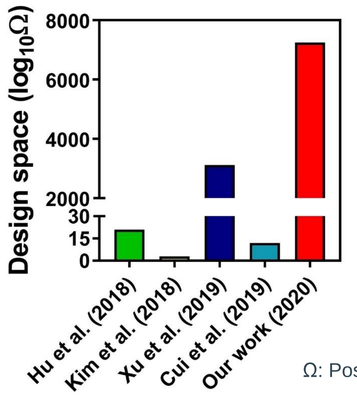
- Magnetically programmed soft structures with complex, fast, and reversible deformation capabilities are transforming soft robotics, wearable devices, and active metamaterials fields.
- The remote applicability and penetration to biological tissues make magnetically responsive structures especially appealing for non-invasive medical applications.
- Magnetically responsive soft structures are enabled by magnetic particles embedded in soft materials.



- Resulting shape transformation depends on the **magnetic programming** of the magnetic particles, **morphology**, and the **applied magnetic fields**.

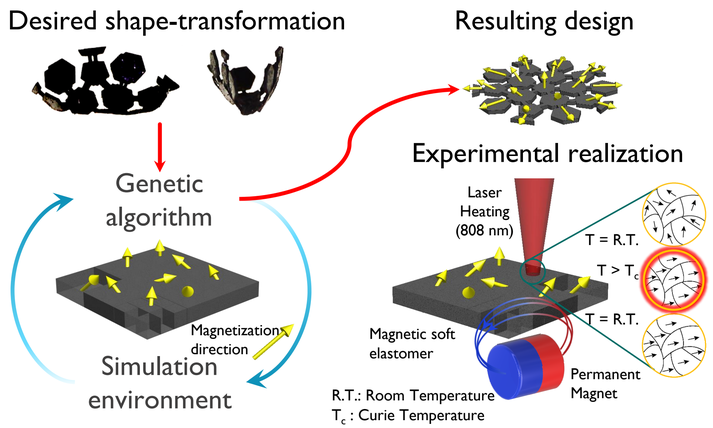
Motivation

- The design space for magnetically programmed soft structures is getting enormous due to the recent advancements in magnetic programming.
- Most of the works still relies on intuition and trial-error based methods that are not feasible for a vast search space.
- Here, we introduce an inverse design methodology to achieve complex shape deformations.



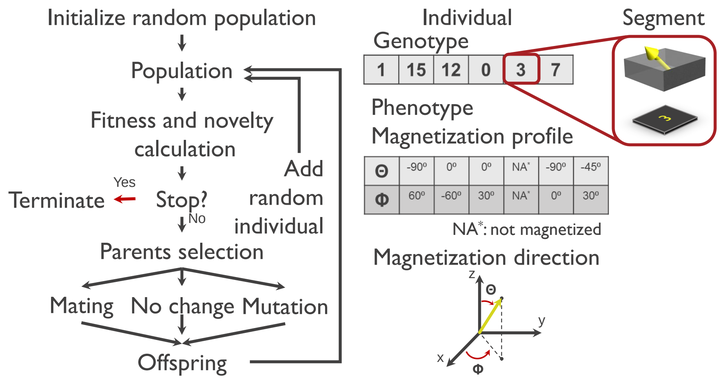
Ω: Possible design variations

Method



- Our method assumes a constant magnetic field that is pre-defined by the user and optimizes the magnetic programming and the morphology of the structure to achieve desired quasi-static shape transformation. For the initial part of this study, morphology is fixed to a beam shape.
- Genetic algorithm searches the design space by the help of a developed simulation environment.
- The resultant design are experimentally realized by heat-assisted magnetic programming.

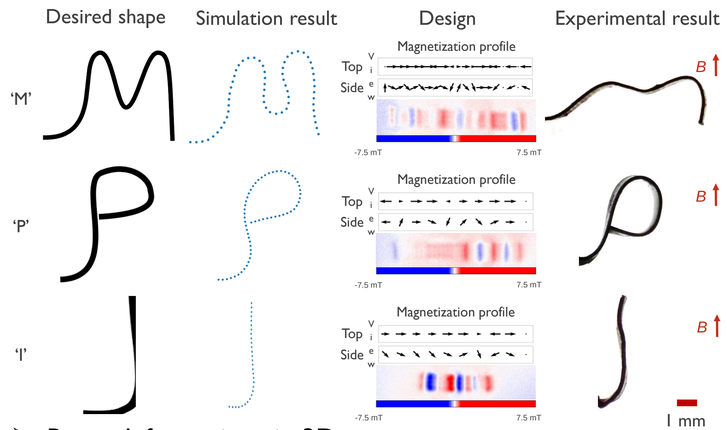
➢ Algorithm



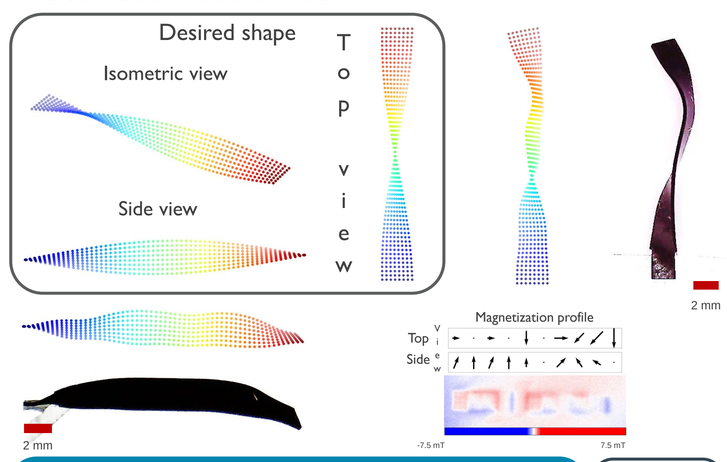
- A genetic algorithm relying on fitness and novelty functions is implemented.

Preliminary results

➢ Beam deformations in 2D



➢ Beam deformations in 3D



Conclusions

- ✓ Simulation-to-reality is shown.
- ✓ Complexity of the deformations exceed the state-of-art.

References

W. Hu et al. (2018). "Small-scale soft-bodied robot with multimodal locomotion," In: Nature, vol. 554, pp. 81–85.

Y. Kim et al. (2018). "Printing ferromagnetic domains for untethered fast-transforming soft materials," In: Nature, vol. 558, pp. 274–279.

T. Xu et al. (2019). "Millimeter-scale flexible robots with programmable three-dimensional magnetization and motions," In: Science Robotics, vol. 4, Issue 29.

J. Cui et al. (2019) "Nanomagnetic encoding of shape-morphing micromachines," In: Nature, vol. 575, pp. 164–168.

Y. Alapan et al. (2020). "Reprogrammable shape morphing of magnetic soft machines," In: Science Advances, vol. 6, no. 38.