# Controlling pattern transformation rates of magnetic microrobotic swarms

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**Abstract**. Reconfigurable microrobotic swarms (microswarms) with transformable morphology hold great potential for biomedical applications, such as targeted drug delivery. The ability to change shapes as quickly as natural animal swarms can endow microswarms with higher adaptability when applied in complex environments. However, achieving on-demand pattern transformation rates control of microswarms remains a challenge. In this work, we propose a strategy for controlling pattern transformation rates of magnetic microswarms by coordinating the inner interactions. Moreover, the strategy is further validated in viscous Newtonian fluids, non-Newtonian biofluids, and dynamic fluids.

## Introduction

Collective behaviors in nature enable living creatures to construct swarms with transformable morphology, which endows them with environmental adaptability far beyond individuals. Inspired by natural swarming behaviors, artificial microswarms capable of performing reversible pattern transformation have been developed [1]. Compared with natural swarms, pattern transformation rates of artificial microswarms are quite lower. For example, the swarm of *Bacillaria paradoxa*, a widely distributed diatom, can reversibly transform between fully stretched and contracted patterns in several to tens of seconds. In contrast, artificial microswarms take more time (minutes or even longer) to complete the same degree of pattern transformation. Controlling pattern transformation rates contributes to enhancing the environmental adaptability of microswarms, which is of great significance for applications in complex biological environments. However, to date, studies on microswarm pattern transformation mainly focus on realizing different types and large degrees of transformation, and strategies for achieving on-demand control of pattern transformation remain unknown.

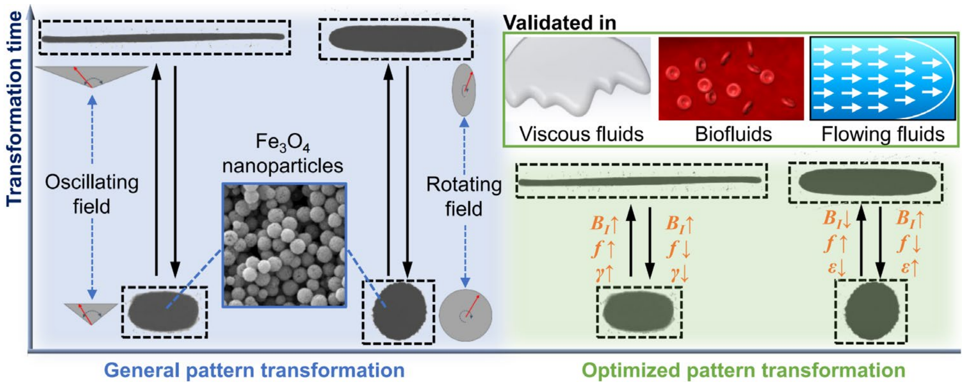


Figure 1: Schematic illustration of microswarm pattern transformation rates control. $B_I$ is the input field strength. $f$ is the input frequency. $\gamma$ and $\varepsilon$ are the field ratio of oscillating and rotating magnetic fields, respectively.

## Results and discussion

In this work, two magnetic colloidal microswarms (*i.e.*, ribbon-like and vortex-like microswarms) with reversible pattern transformation ability are used to investigate the transformation rates control strategy. A theoretical model is constructed to quantitively characterize the magnetic and hydrodynamic interactions between nanoparticle chains, and pattern transformation experiments are conducted under different field parameters. Based on the theoretical and experimental results, the strategy to control pattern transformation rates by adjusting the field parameters (*i.e.*, field ratio, input field strength, and frequency) is proposed (see Figure 1) [2]. We demonstrate utilizing the proposed strategy to increase pattern transformation rates of the ribbon-like and vortex-like microswarms to 568% and 820% of the original, respectively. We further validate that the strategy is applicable in viscous Newtonian fluids, non-Newtonian biofluids, and flowing fluids. This work provides a fundamental understanding of small-scale swarming behaviors, which endows a new perspective for improving the controllability and active adaptability of microswarms.

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## References

[1] Yang L. D., Yu J. F., Yang S. H., Wang B., Nelson B. J., Zhang L. (2022) A Survey on Swarm Microrobotics. *IEEE Trans. Robot.* **38**: 1531-1551.

[2] Yang S. H., Wang Q. Q., Jin D. D., Du X. Z., Zhang L. (2022) Probing Fast Transformation of Magnetic Colloidal Microswarms in Complex Fluids. *ACS Nano.* DOI: https://doi.org/10.1021/acsnano.2c07948.