# 3D Control of Magnetically-Driven Microrobots in Viscoelastic Medium

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## Introduction

Untethered microrobots have important applications in medicine, such as targeted drug delivery and treatment of vascular diseases. To address these clinical applications, untethered microrobots must respond controllably to external stimuli. The magnetic field produced by electromagnetic- and permanent magnet-based manipulation systems is a viable option as an external stimulus. However, electromagnetic-based manipulation systems have shortcomings of being scaled up to the size of *in vivo* application. In this study, we present a permanent magnet-based robotic control system with open configuration using two synchronized rotating magnetic fields (Figure 1(a)), which is developed to generate time-varying rotating magnetic fields to actuate a magnetic microrobot (Figure 1(b)). Moreover, the initial magnetic field distribution in system working space is displayed in Figure 1(c).

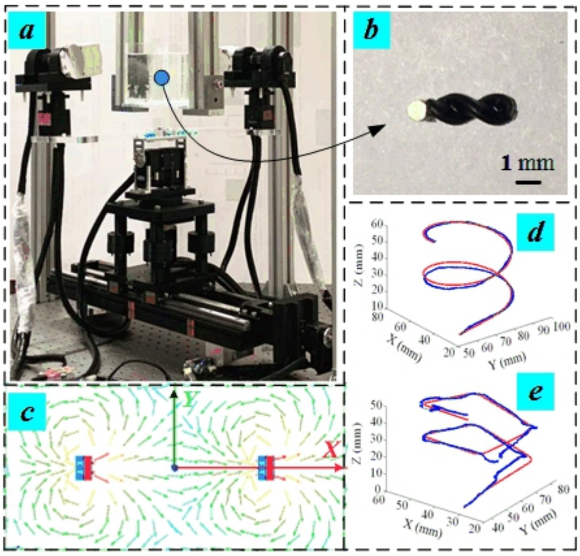


Figure 1. Isometric view of the robotic control system is shown in (a). Initial magnetic field distribution in system working space is displayed in (b). The microrobot (c) swims controllably along 3D -circular and -square trajectories, with the planned (red) and actual trajectories (blue) being indicated, as shown in (d) and (e) respectively.

## Methods

First, we demonstrate the capability of the permanent magnet-based robotic system to generate the rotating magnetic fields. The system provides four degrees of freedom to fix two permanent magnets in 3D space. A container is placed in the middle of two synchronized rotating permanent magnets. Second, we model the forward kinematics and extract the centroid trajectories of the two magnets, then the orientation of the magnetic field at the position of the microrobot is acquired based on an exact model. The inverse kinematics problems of the system are solved by utilizing an iterative optimization algorithm to determine the joint angles. Third, we conduct viscoelastic experiments of controling microrobot moving at a circular and square trace in an agar gel tissue phantom (Figures 1(d) and 1(e)). Moreover, the influence of the microrobot's geometric features on its swimming characteristics in viscoelastic environment is also investigated.

## Results and Conclusion

The experimental results demonstrate that the maximum error from the tracked trajectory is 4.5 mm. In conclusion, we have achieved 3D open-loop control for the magnetically-driven microrobot. Our control method will enable us to access natural pathways and hard to reach regions using magnetic actuation.