REALIZATION AND CONTROL OF A SWARM OF MAGNETOTACTIC BACTERIA

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ABSTRACT

Over the last two decades, a range of minimal invasive surgery (MIS) techniques have been presented to reduce patient recovery time and risks of infection during the surgery. In MIS, incisions are significantly small, as opposed to conventional surgery [1]. The operating range of the needle insertion is limited by the reachability of the needle tip within the human body due to the presence of obstructions. Therefore, effort has been dedicated to the development of magnetic drug carriers (e.g. microparticles, microrobots, magnetotactic bacteria) with real-time control. These magnetic drug carriers can be steered to the location where drugs need to be administered. However, steering a real-time fully controllable magnetic drug carrier is a challenging task and requires both tracking and characterization of the position and the properties of the magnetic carrier, respectively.

Utilization of self-propelled magnetotactic bacteria (MTB) as magnetic drug carriers eliminates the need for external means of propulsion. In order to model MTB, we characterize their magnetic dipole moment to realize the dynamical model of a single MTB [2]. In addition, we use this model to design closed-loop control system to control the motion of the MTB inside capillary tubes and micro fluidic maze [3, 4]. The next step towards transport and delivery of greater amounts of drugs requires higher MTB density. Therefore, a method is needed to investigate the synchronized and controlled characteristics of a swarm of MTB.

In this study, the viability of controlling a swarm of MTB is tested *in vitro* using magnetic fields to steer the MTB towards a mechanical constriction, as shown in Fig. 1. In our approach, a uniform magnetic field is imposed to force the MTB into one direction parallel to the longitudinal axis of the funnel (Fig. 1). Thus changing a forward driving thrust force along the magnetic fields into a shifted force in the direction of the center of the funnel, to form a swarm of MTB at the 30 μm wide semi-circular recess. Second, the magnetic field is reversed to move the swarm of MTB away from the funnel recess. Subsequently, magnetic fields are generated to control the swarm of MTB. Through the guidance of open- and closed-loop control, the average velocity, region-of-convergence (ROC) and accuracy of controlling such a swarm are investigated. A wide distribution of the population can affect the average velocity of the swarm of MTB. We compare the velocity of a swarm of MTB to the velocity of single MTB. Furthermore, the diameter of the ROC determines the accuracy of the control system in the steady-state.

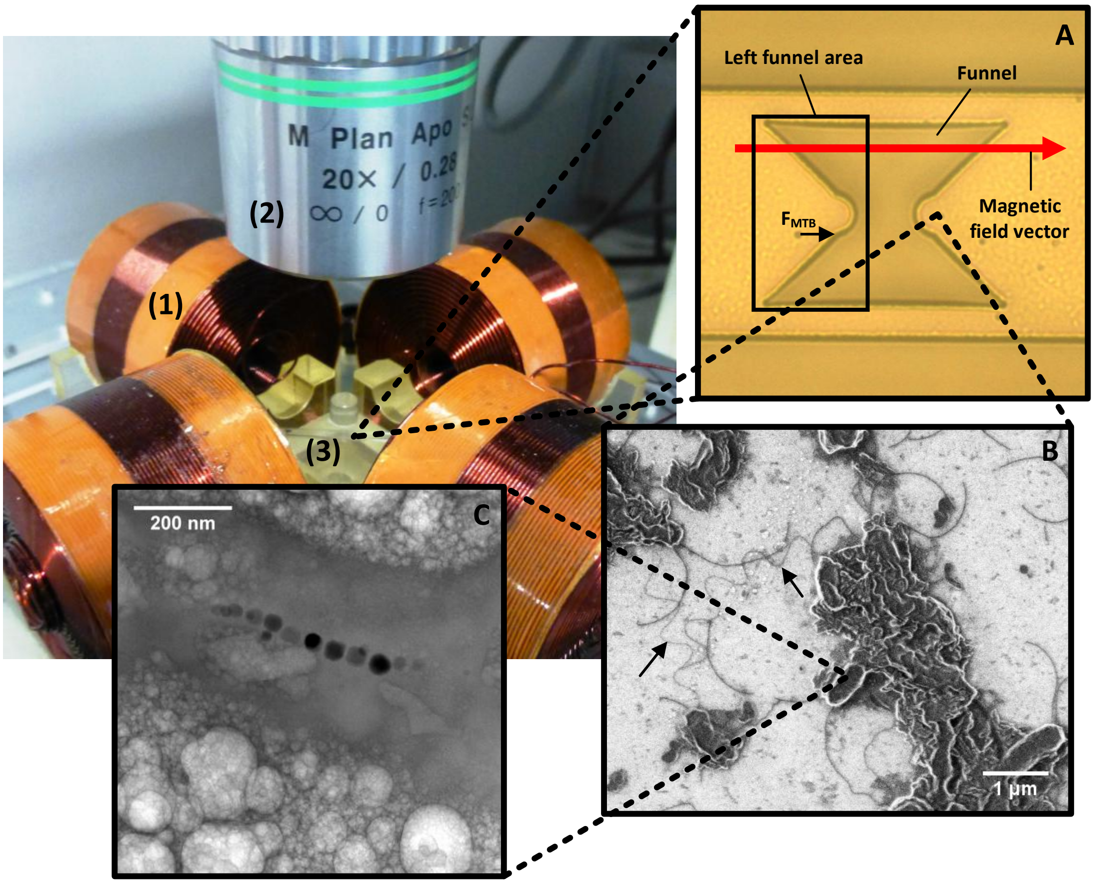

Fig. 1 Magnetic-based manipulation system with electromagnets (1), microscope system (2), micro fluidic chip reservoir and X-/Y-motion stage (3). Inset A: Micro fluidic channel with a centralized mirrored funnel shape parallel to the channel, with a 30 µm wide recess at the center of both sides. Red line schematically indicates magnetic field for the purpose of steering Magnetotactic Bacteria (MTB) into the center of the funnel. Inset B: High Resolution Scanning Electron Microscope image of MTB and flagella indicated by the arrows. Inset C: Transmission Electron Microscope image showing a Fe_3O_4 crystal chain enveloped within the MTB magnetosome vesicles.

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