Research Grants for PhD from the China Scholarship Council

Details of the PhD proposal

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- **PhD proposal title**:

  Modeling and simulation of magnetic microrobotic systems

- **Keywords**: microrobotics, magnetic microrobot, magnetic microrobotic systems, electromagnetic actuation, computational modeling
- **Supervision**:
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1 PhD proposal description

1.1 Context

Micromanipulation platforms that magnetically guide microrobots attracted increasing attention in recent years, mainly because of their high potential in medical and bio-engineering applications [1–8]. Specifically, magnetic navigation is an actuation technology in which magnetic fields are used to wirelessly navigate microrobots containing magnetic materials usually in fluid medium. Commonly, the term "microrobot" refers to a controllable device with a size below millimeters scale. Microrobots can then access complex and narrow regions of the human body as well as manipulate down to subcellular entities [2, 9–12]. However, integrating on-board components is difficult due to their limited size. To improve the scientific and clinical outcomes of these tiny agents, developing suitable and reliable actuation systems is essential. As a newly emerging field that has progressed in recent years, magnetic actuation systems offer a harmless and effective approach for the remote control of miniature robots via a dynamic magnetic field. To this purpose, external magnetic fields are applied to propel and steer the magnetic robots to the targeted area and to accomplish a specific task. To be able to achieve all of this efficiently, the design of the magnetic microrobotic system needs to be further investigated.

1.2 State of the art

1.2.1 Magnetic microrobot navigation

Magnetically actuated microrobots have been proposed for numerous applications, as their small scales enable the access to complex environments [1, 2, 5, 6, 8]. Basically, an external magnetic actuation system wirelessly transfer power to set microrobots in motion. Motion control technology enables the development of magnetic microrobots with various controllable motion modalities (e.g. bead steering, helical swimmer, etc.), high motion accuracy (e.g. closed-loop control), and high task efficiency (e.g. motion planning) [6, 13, 14]. These advances promote real microrobotics applications in environments that may be complex and dynamic. In addition, the ability to exert independent control over a group of microrobots working together on a task has potential to increase task speed and capability [6]. Controlling swarms on the order of hundreds to thousands micro/nano-robots is one of the great challenges in magnetic microrobotics [3]. Contrarily to individual or multi-agent control, the interactive force should not be ignored. This aspect increases the difficulty of the theoretical modeling of swarm behaviors of several magnetic microrobots. Simulation becomes then a powerful tool for their control. To date, global input are the only feasible method to control a swarm of microrobots [15, 16].

1.2.2 Magnetic actuation system

In remote magnetic navigation, magnetic fields are generated by an external magnetic actuation setup that consists of magnets [5–8, 14]. These are either strong permanent magnets, which are rotated or translated in order to modulate the generated magnetic field, or electromagnets where the magnetic fields are modulated by the amount of electrical current that is running through conductive windings. A magnetic actuation platform using electromagnets is commonly referred as an electromagnetic actuation (EMA) system.
There are advantages and disadvantages to both approaches. Permanent magnet-based systems can be less expensive to manufacture at smaller-scales, magnetic field modeling is straightforward, and access may be easier, since field control can be achieved with fewer magnets. EMA can achieve larger field strengths, allow for independent control of magnetic gradients, and, in contrast to permanent magnets, can be "switched off." In any case, the appropriate number, size, shape and mobility of magnets must first be considered [17].

1.3 Objective

This research work aims to further investigate the use of magnetic actuation system to achieve more efficient control of magnetic microrobots, considering in particular the guidance of a swarm of micro/nano-robots. The goal is then to develop a mathematical approach to efficiently model, simulate and control the magnetic field. The developed model should take into account constraints from the the magnetic microrobotic system, e.g. by solving an optimization problem at regular time intervals. It is also important to determine the appropriate shape of the magnetic field, which may not necessarily be uniform as usually considered.

The different steps of this research work are the following :

1. State of art study on modeling of magnetic microrobotic system;
2. Modeling and simulation of the magnetic field generated by a magnetic actuation system;
3. Optimal design of a multipole-magnet platform;
4. Control of the magnetic field to drive single swarm or multiple magnetic microrobots;

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