

Weekly report

1 My Accomplishments this week

1.1 Project 1: Massive Uniform Control

- Joystick GUI: created a joystick GUI for all directions global control via EM system
- EM system: identified the dimension of the workspace, the magnetic properties of the EM system (uniformity, magnitude)
- Preliminary aggregation: used the joystick and captured a series of screenshot for ferrous particle aggregation
- RSS poster
- Literature review: Berg, H. C. (1993). Random walks in biology. Princeton University Press.
- Literature review: Cheang, U. K., Lee, K., Julius, A. A., & Kim, M. J. (2014). Multiple-robot drug delivery strategy through coordinated teams of microswimmers. *Applied physics letters*, 105(8), 083705.
- Literature review: Cheang, U. K., & Kim, M. J. (2015). Self-assembly of robotic micro-and nanoswimmers using magnetic nanoparticles. *Journal of Nanoparticle Research*, 17(3), 1-11.
- Literature review: Zhang, J., & Diller, E. (2015, September). Millimeter-scale magnetic swimmers using elastomeric undulations. In *Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on* (pp. 1706-1711). IEEE.
- Literature review: Zhang, J., Jain, P., & Diller, E. Independent Control of Two Millimeter-Scale Soft-Bodied Magnetic Robotic Swimmers.
- Literature review: Regtmeier, A., Wittbracht, F., Rempel, T., Mill, N., Peter, M., Weddemann, A., ... & Htten, A. (2012). Uniform growth of clusters of magnetic nanoparticles in a rotating magnetic field. *Journal of Nanoparticle Research*, 14(8), 1-5.
- Literature review: Wittbracht, F., Eickenberg, B., Weddemann, A., & Htten, A. (2011). Towards a programmable microfluidic valve: Formation dynamics of two-dimensional magnetic bead arrays in transient magnetic fields. *Journal of Applied Physics*, 109(11), 114503.
- Literature review: Koser, A. E., Keim, N. C., & Arratia, P. E. (2013). Structure and dynamics of self-assembling colloidal monolayers in oscillating magnetic fields. *Physical Review E*, 88(6), 062304.
- Literature review: Gao, Y., van Reenen, A., Hulsen, M. A., de Jong, A. M., Prins, M. W., & den Toonder, J. M. (2013). Disaggregation of microparticle clusters by induced magnetic dipole-dipole repulsion near a surface. *Lab on a Chip*, 13(7), 1394-1401.
- Literature review: Kappe, D., & Htten, A. Formation of particle clusters from rotating particle chains.



Path-Planning and Neighbor Interactions with Microbot Swarms

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Untethered Microbot Swarms

Features:

- a) Work in large populations ($10^2 - 10^{14}$)
- b) Follow global inputs
- c) Easy to fabricate and assemble

Challenges:

- a) Limited on-board computation and communications
- b) Dependence on external fields for actuation
- c) Global inputs lead to symmetric output

Potential Applications:

- a) Microscale fabrication
- b) Minimally invasive surgery
- c) Targeted drug delivery in vivo

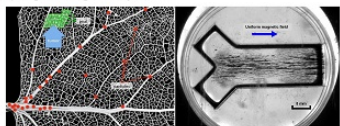


Figure 1: Schematic of targeted drug delivery in human vascular system, and ferrous particles in the electromagnetic system

Break Symmetry with Environment

Our recent research in Fig. 2 investigated how environment (such as obstacles, walls, or friction) can shape and control particle swarms in 2D workspace using uniform control inputs. This input is applied globally and hence the swarm system is under-actuated in a free workspace.

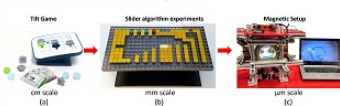


Figure 2: Experiments of (a) the cm scale Tilt™ Game and (b) mm scale slider setup have given insight into developing algorithms specific to global control. Structured algorithms can be developed for micron scale particle control (c).

Simulation: Aggregation of Particles

Simulation Setup:

- Particle size \ll workspace corridors, as in Fig. 1(a)
- The world is a 2D planar bounded connected maze
- A control sequence m moves all particles up/down/left/right in an ordered sequence of moves m_i , where each $m_i \in \{u, d, l, r\}$
- A representative command sequence is $\{u, r, d, l, d, r, u, \dots\}$
- Particles may overlap and occupy the same space

Greedy Algorithm

Greedy algorithms strike a balance between number of moves and computation time. Testing on large workspaces comparable to our vascular network of interest gives consistent results (Fig. 3). Each algorithm iteratively combines pairs of particles, but use different pairs:

- 1) Closest pair of particles
- 2) Furthest pair of particles
- 3) First pair of particles in scan

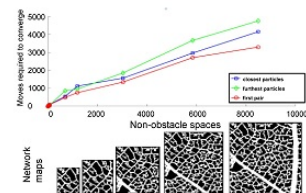


Figure 3: Number of moves taken in large worlds by 3 greedy algorithms. Algorithm first pair converges faster than other algorithms.

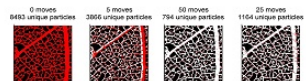


Figure 4: Screenshot of greedy algorithm simulation in a vascular system. Robots collapse into clusters. When only one cluster remains, the swarm is converged.

Hardware Implementation

Experiment Setup:

- $20 \times 20 \times 5.6$ mm³ container, made of 2.8 mm acrylic
- Particles are natural black iron oxide ≈ 30 μ m
- 2 pairs of orthogonal coils (xy plane) of the electromagnetic system provide uniform magnetic fields ($\pm 5.5\%$), up to 20 mT in arbitrary 2D directions within the container

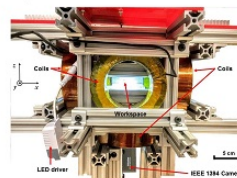


Figure 5: Electromagnetic system for microbots

Open-loop Particle Aggregation

Currently, we are working on low Reynolds number ($Re < 0.1$), particle swarm manipulation, under uniform input, in a customized electromagnetic system. The major challenges of controlling a massive number of particles are:

- a) Heuristic pathfinding algorithm in vivo
- b) Regulating particles aggregation and concentration
- c) Robust control and navigation of swarms with delay

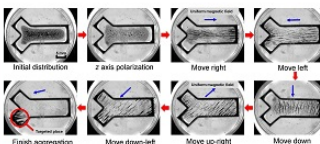


Figure 6: Preliminary research on open-loop aggregation with uniform magnetic fields is informed by human-in-the-loop studies, using a 6-channel joystick with visual feedback.



Figure 1: RSS poster

2 My Goals for next week

- RSS Conference