Controlling a Swarm With Global Inputs: Varying Controller Type

Shiva Shahrokhi, Chris Ertel and Aaron T. Becker

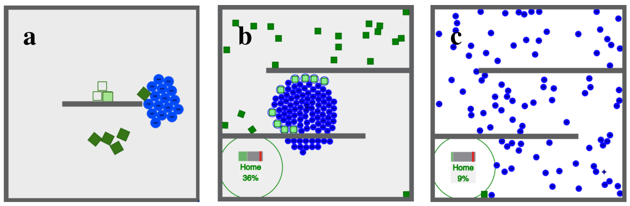

Fig. 1. Screenshots from our online experiments controlling multi-particle systems with limited, global control. **(a)** Comparing 3 control architectures to assemble **(b)** Comparing 3 control architectures to forage. **(c)** Comparing 3 control architectures to escape

***Abstract*— There are driving applications for large populations of tiny robots in robotics, biology, and chemistry. These robots often lack onboard computation, actuation, and communication. Instead, these "robots" are particles carrying some payload and the particle swarm is controlled by a shared, global control input such as a uniform magnetic gradient or electric field. Different controller types are used. Repulsive and attractive controllers are the Requiring a small, rigid obstacle suspended in the middle of the workspace is a strong constraint, especially in 3D. This paper relaxes that constraint, and provides position control algorithms that only require interactions with the boundaries. Both in vivo and artificial environments often have boundaries. We assume that particles in contact with the boundaries have zero velocity if the global control input pushes the particle into the wall. This paper provides a shortest-path algorithm for positioning a two-particle swarm, and a generalization to positioning an n-particle swarm. Results are validated with simulations and a hardware demonstration.**

I. Online Experiment

The goal of these online experiments is to test several scenarios involving large-scale human-swarm interaction (HSI), and to do so with a statistically-significant sample size. Towards this end, we have created SwarmControl.net: an open-source, online testing platform suitable for inexpensive deployment and data collection on a scale not yet seen in swarm robotics research. Screenshots from this platform are shown in Fig. 1. All code and experimental results are online at [**?**].

A. Implementation

Our web server generates a unique identifier for each participant and sends it along with the landing page to the participant. A script on the participant's browser runs the experiment and posts the experiment data to the server.

Anonymized human subject data was collected under IRB #14357-01.

II. Human-swarm interaction results

a) Varying control–Assembly: Ultimately, we want to use swarms of particles to build things. This experiment compared different control architectures modeled after real-world devices.

We compared attractive and repulsive control with the global control used for the other experiments. The attractive and repulsive controllers were loosely modeled after scanning tunneling microscopes (STM), but also apply to magnetic manipulation, e.g. [1] and biological models, e.g. [2]. STMs can be used to arrange atoms and make small assemblies, as described in [3]. An STM tip is charged with electrical potential, and used to repel like-charged or to attract differently-charged molecules. In contrast, the global controller uses a uniform field (perhaps formed by parallel lines of differently-charged conductors) to pull molecules in the same direction. The experiment challenged players to assemble a three-block pyramid with a swarm of 16 particles.

The results were conclusive, as shown in Fig. 2a: attractive control was the fastest, followed by global control, with repulsive control a distant last. The median time using repulsive control was four times longer than with attractive control. Using ANOVA analysis, we reject the null hypothesis that all controllers are equivalent, with p-value 3.37×10^{-32}.

b) Varying control–Foraging: Collecting and delivering resources is necessary for drug delivery. This experiment also compared attractive and repulsive control with the global control used for the other experiments. The experiment challenged players to collect particles using a swarm of 100 particles and return the particles to a home region. The particles encapsulate the particles on contact.

The results were conclusive, as shown in Fig. 2.b: global control was the fastest, followed by repulsive control, with attractive control last. Using ANOVA analysis, we reject the null hypothesis that all controllers are equivalent, with p-value 2.96×10^{-6}.

References

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[3] P. Avouris, "Manipulation of matter at the atomic and molecular levels," *Accounts of chemical research*, vol. 28, no. 3, pp. 95–102, 1995.

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Authors are with the Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77204 USA {sshahrokhi2, atbecker}@uh.edu

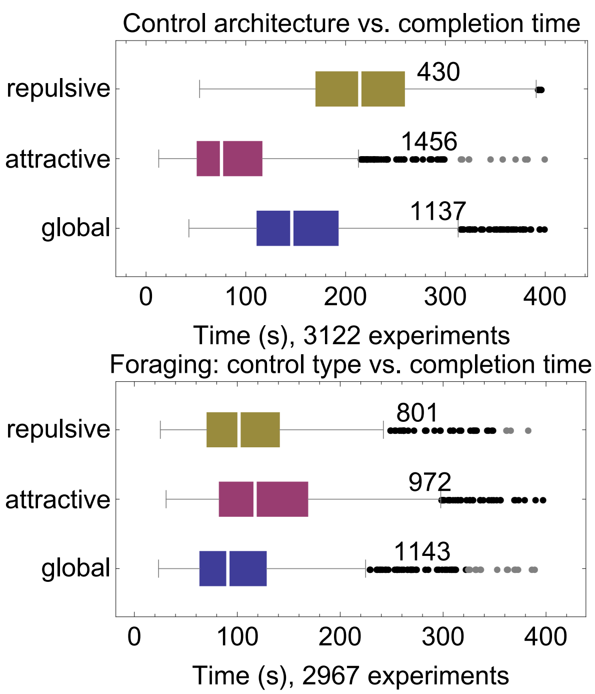

Fig. 2. Completion time depends on both the task and the control type. Left: Attractive control resulted in the shortest completion time and repulsive the longest for building a three-block pyramid. Right: in the foraging test, global control resulted in the shortest completion time and attractive the longest.