

Shaping a Swarm Using Wall Friction and a Shared Control Input

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Abstract—Micro- and nano-robots can be manufactured in large numbers. Large numbers of micro robots are required in order to deliver sufficient payloads, but the small size of these robots makes it difficult to perform onboard computation. Instead, these robots are often controlled by a global, broadcast signal. In our previous work we focused on a block-pushing task, where a swarm of robots pushed a larger block through a 2D maze. One surprising result was that humans that only knew the swarm’s mean and covariance completed the task faster than humans who knew the position of every robot [?]. Inspired by that work, we proved that we can control the mean position of a swarm and that with an obstacle we can control the swarm’s position variance (σ_x and σ_y). We then wrote automatic controllers which could complete a block pushing task, but these controllers had some limitations [?]. One of the limitations was that we could only compress our swarm along the world x and y axes, and could not navigate workspaces with narrow corridors with other orientations. One solution to these problems would be a controller that regulates the swarm’s position covariance, σ_{xy} . For controlling σ_{xy} , we prove that the swarm position covariance σ_{xy} is controllable given boundaries with non-zero friction. We then prove that two orthogonal boundaries with high friction are sufficient to arbitrarily position a swarm of robots. We conclude by designing controllers that efficiently regulate σ_{xy} .

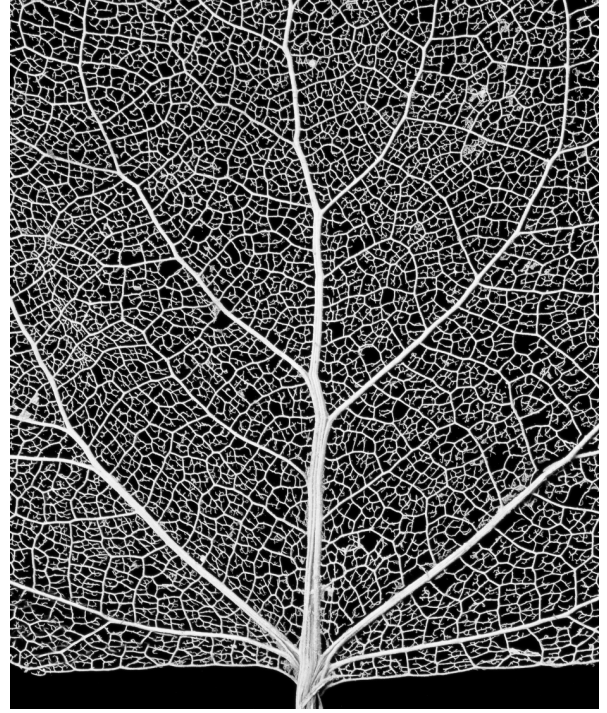


Fig. 1. Several real vascular networks exist in real world, which navigating a swarm with a global input would be a challenge because of the branches in the way.

I. INTRODUCTION

II. THEORY

III. SIMULATION

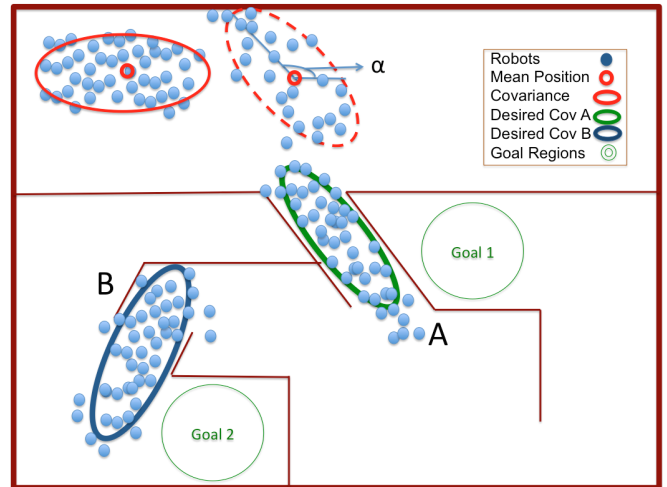
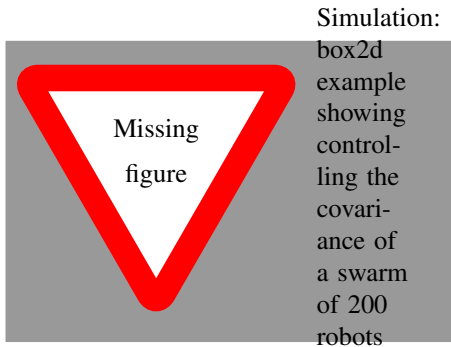


Fig. 2. We can control covariance of the swarm by using friction.

Algorithm 1 GenerateDesired x -spacing(s_1, s_2, e_1, e_2, L)

Require: Knowledge of starting (s_1, s_2) and ending (e_1, e_2) positions of two robots. $(0, 0)$ is bottom corner, s_1 is topmost robot, L is length of the walls. Current position of the robots are (r_1, r_2) .

Ensure: $r_{1y} - r_{2y} \equiv s_{1y} - s_{2y}$

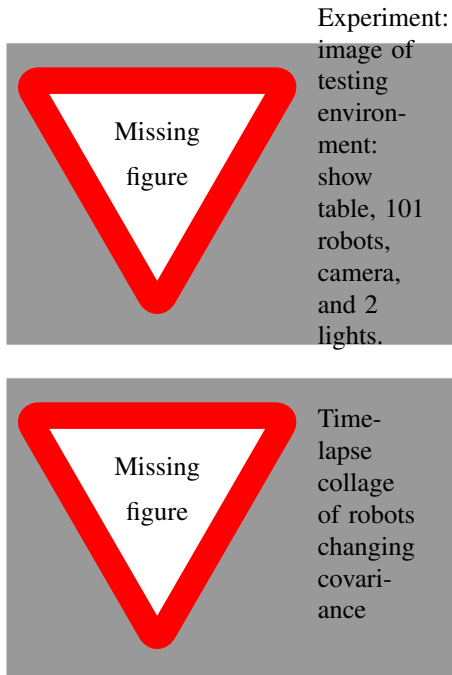
- 1: $\Delta s_x \leftarrow s_{1x} - s_{2x}$
- 2: $\Delta e_x \leftarrow e_{1x} - e_{2x}$
- 3: $r_1 \leftarrow s_1, r_2 \leftarrow s_2$
- 4: **if** $\Delta e_x < 0$ **then**
- 5: $m \leftarrow (L - \max(r_{1x}, r_{2x}), 0)$ \triangleright Move to right wall
- 6: **else**
- 7: $m \leftarrow (-\min(r_{1x}, r_{2x}), 0)$ \triangleright Move to left wall
- 8: **end if**
- 9: $m \leftarrow m + (0, -\min(r_{1y}, r_{2y}))$ \triangleright Move to bottom
- 10: $r_1 \leftarrow r_1 + m, r_2 \leftarrow r_2 + m$ \triangleright Apply move
- 11: **if** $\Delta e_x - (r_{1x} - r_{2x}) > 0$ **then**
- 12: $m \leftarrow (\min(\|\Delta e_x - \Delta s_x\|, L - r_{1x}), 0)$ \triangleright Move right
- 13: **else**
- 14: $m \leftarrow (-\min(\|\Delta e_x - \Delta s_x\|, r_{1x}), 0)$ \triangleright Move left
- 15: **end if**
- 16: $m \leftarrow m + (0, \epsilon)$ \triangleright Move up
- 17: $r_1 \leftarrow r_1 + m, r_2 \leftarrow r_2 + m$ \triangleright Apply move
- 18: $\Delta r_x = r_{1x} - r_{2x}$
- 19: **if** $\Delta r_x \equiv \Delta e_x$ **then**
- 20: $m \leftarrow (e_{1x} - r_{1x}, e_{1y} - r_{1y})$
- 21: $r_1 \leftarrow r_1 + m, r_2 \leftarrow r_2 + m$ \triangleright Apply move
- 22: **return** (r_1, r_2)
- 23: **else**
- 24: **return** GenerateDesired x -spacing(r_1, r_2, e_1, e_2, L)
- 25: **end if**

Algorithm 2 GenerateDesired y -spacing(s_1, s_2, e_1, e_2, L)

Require: Knowledge of starting (s_1, s_2) and ending (e_1, e_2) positions of two robots. $(0, 0)$ is bottom corner, s_1 is rightmost robot, L is length of the walls. Current position of the robots are (r_1, r_2) .

Ensure: $r_{1x} - r_{2x} \equiv s_{1x} - s_{2x}$

- 1: $\Delta s_y \leftarrow s_{1y} - s_{2y}$
- 2: $\Delta e_y \leftarrow e_{1y} - e_{2y}$
- 3: $r_1 \leftarrow s_1, r_2 \leftarrow s_2$
- 4: **if** $\Delta e_y < 0$ **then**
- 5: $m \leftarrow (L - \max(r_{1y}, r_{2y}), 0)$ \triangleright Move to top wall
- 6: **else**
- 7: $m \leftarrow (-\min(r_{1y}, r_{2y}), 0)$ \triangleright Move to bottom wall
- 8: **end if**
- 9: $m \leftarrow m + (0, -\min(r_{1x}, r_{2x}))$ \triangleright Move to left
- 10: $r_1 \leftarrow r_1 + m, r_2 \leftarrow r_2 + m$ \triangleright Apply move
- 11: **if** $\Delta e_y - (r_{1y} - r_{2y}) > 0$ **then**
- 12: $m \leftarrow (\min(\|\Delta e_y - \Delta s_y\|, L - r_{1y}), 0)$ \triangleright Move top
- 13: **else**
- 14: $m \leftarrow (-\min(\|\Delta e_y - \Delta s_y\|, r_{1y}), 0)$ \triangleright Move bottom
- 15: **end if**
- 16: $m \leftarrow m + (0, \epsilon)$ \triangleright Move right
- 17: $r_1 \leftarrow r_1 + m, r_2 \leftarrow r_2 + m$ \triangleright Apply move
- 18: $\Delta r_y = r_{1y} - r_{2y}$
- 19: **if** $\Delta r_y \equiv \Delta e_y$ **then**
- 20: $m \leftarrow (e_{1x} - r_{1x}, e_{1y} - r_{1y})$
- 21: $r_1 \leftarrow r_1 + m, r_2 \leftarrow r_2 + m$ \triangleright Apply move
- 22: **return** (r_1, r_2)
- 23: **else**
- 24: **return** GenerateDesired y -spacing(r_1, r_2, e_1, e_2, L)
- 25: **end if**



Algorithm 3 Getting desired Space

Require: Knowledge of the starting and ending positions of the two robots s_1 & s_2 & e_1 & e_2 and L length of the walls. Current position of the robot will be showed as r .

- 1: $e_{1x} - e_{2x} = \Delta e_x$
- 2: $e_{1y} - e_{2y} = \Delta e_y$
- 3: $s_{1x} - s_{2x} = \Delta s_x$
- 4: $s_{1y} - s_{2y} = \Delta s_y$
- 5: **if** $\Delta s_x < \Delta s_y$ **then**
- 6: Do XSpace
- 7: Do YSpace
- 8: **else**
- 9: Do YSpace
- 10: Do XSpace
- 11: **end if**

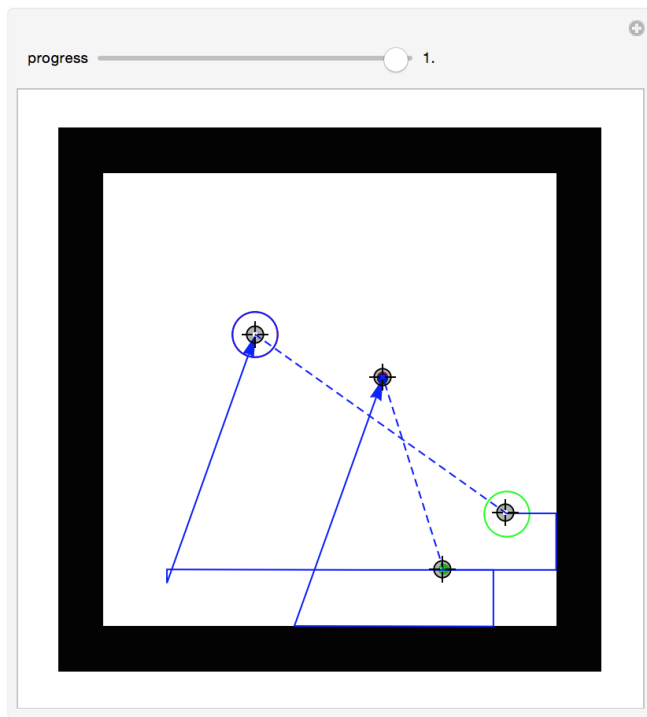


Fig. 3. Using friction to move two robots from the starting point to their end point.

