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 that 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}.**

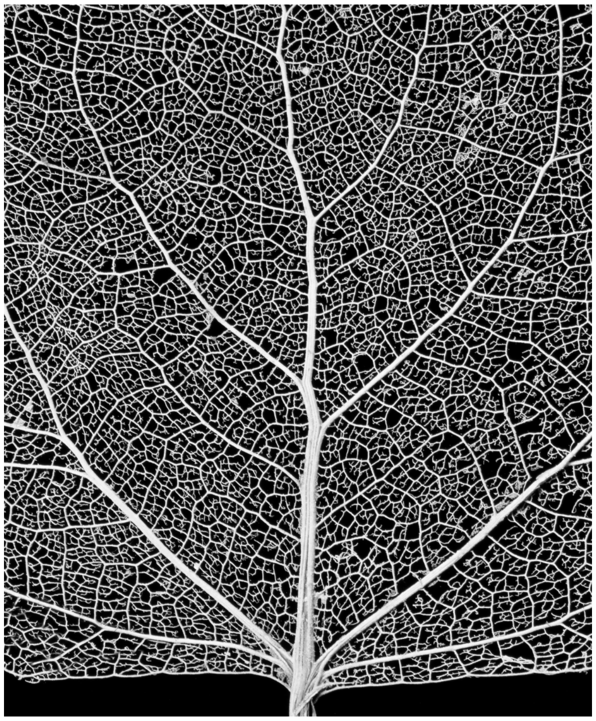
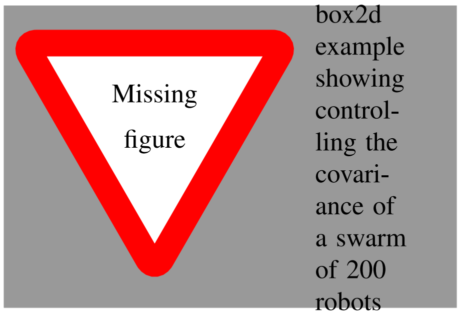


Fig. 1. Several real vascular networks exist in real world, which navigating a swarm with a global input would be a challenge because of the branches in the way.

I. Introduction

II. Theory

III. Simulation



Simulation: box2d example showing controlling the covariance of a swarm of 200 robots

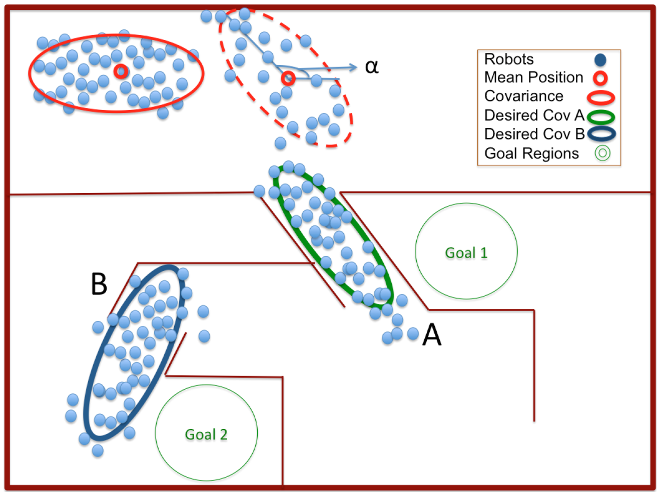


Fig. 2. We can control covariance of the swarm by using friction.

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Algorithm 1 Getting desired X-space

```
Require: Knowledge of the starting and ending positions of
    the two robots $s_1$ (topper robot) & $s_2$ (lower robot) &
    $e_1$ & $e_2$ and $L$ length of the walls. Current position of
    the robot will be showed as $r$.
Ensure: $\Delta y(t) = \Delta y(0)$
 1: $e_{1x} - e_{2x} = \Delta e_x$
 2: $s_{1x} - s_{2x} = \Delta s_x$
 3: if $\Delta e < 0$ then
 4:     Move almost to right wall
 5: else
 6: Move almost to left wall
 7: end if
 8: Move to bottom
 9: if $\Delta e_x - \Delta x > 0$ then
10:     Update current position of the robots: $r_1$ , $r_2$
11:     Go right for $min(\|\Delta e_x - \Delta s_x\|, L - r_{1x})$
12: else
13: Go left for $-min(\|\Delta e_x - \Delta s_x\|, r_{1x})$
14: end if
15: Move $\epsilon$ up
16: Update current position of the robots: $r_1$ , $r_2$
17: $\Delta r_x = r_{1x} - r_{2x}$
18: if $\Delta r_x = \Delta e_x$ then
19:     Go to $e_1$, $e_2$
20:     Return
21: else
22: Do the algorithm again with the inputs of $r_1$, $r_2$, $e_1$, $e_2$
23: end if
```

Algorithm 2 Getting desired Y-space

```
Require: Knowledge of the starting and ending positions of
    the two robots $s_1$ (right robot) & $s_2$ (left robot) & $e_1$
    & $e_2$ and $L$ length of the walls. Current position of the
    robot will be showed as $r$.
Ensure: $\Delta x(t) = \Delta x(0)$
 1: $e_{1y} - e_{2y} = \Delta e_y$
 2: $s_{1y} - s_{2y} = \Delta s_y$
 3: if $\Delta e < 0$ then
 4:     Move almost to up wall
 5: else
 6: Move almost to down wall
 7: end if
 8: Move to right
 9: if $\Delta e_y - \Delta s_y > 0$ then
10:     Update current position of the robots: $r_1$ , $r_2$
11:     Go right for $min(\|\Delta e_y - \Delta s_y\|, L - r_{1y})$
12: else
13: Go left for $-min(\|\Delta e - \Delta s_y\|, r_{1y})$
14: end if
15: Move $\epsilon$ left
16: Update current position of the robots: $r_1$ , $r_2$
17: $\Delta r_y = r_{1y} - r_{2y}$
18: if $\Delta r_y = \Delta e_y$ then
19:     Go to $e_1$, $e_2$
20:     Return
21: else
22: Do the algorithm again with the inputs of $r_1$, $r_2$, $e_1$, $e_2$
23: end if
```

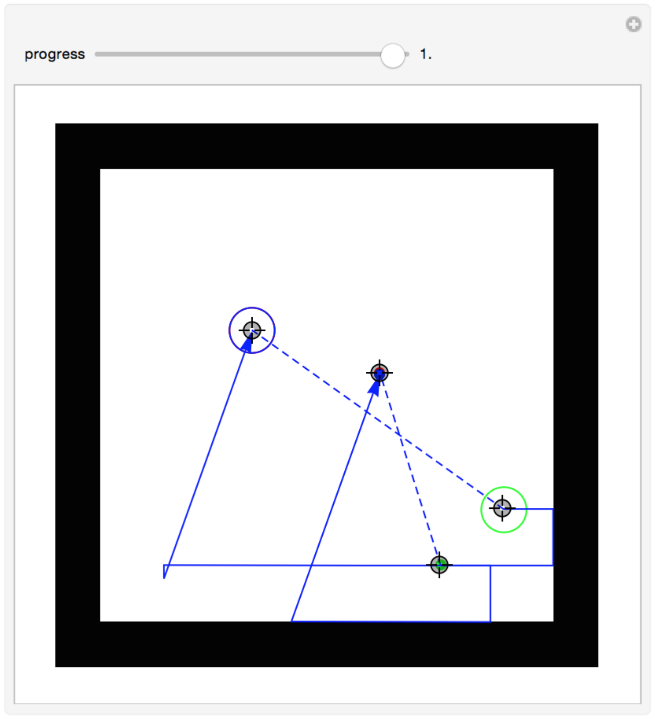

Fig. 3. Using friction to move two robots from the starting point to their end point.

Experiment: image of testing environment: show table, 101 robots, camera, and 2 lights.

Time-lapse collage of robots changing covariance

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
```

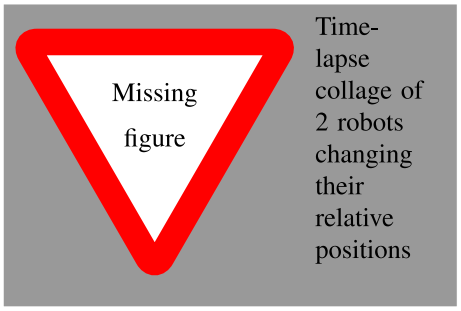
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figure
Time-lapse collage of 2 robots changing their relative positions