MAE 598: Multi-Robot Systems

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Lectures 25-26: Cooperative Manipulation

Classifying Collective Transport Strategies

Lynne Parker, “Collective Manipulation and Construction,” 2015

- Local knowledge only vs. some required global knowledge (ex. of team size, location, payload characteristics)
- Homogeneous teams vs. heterogeneous teams (different types of robots, teams with leaders/followers)
- Type of environment: 2D, 3D, obstacle-free, cluttered, static, dynamic
- Dependent on fully functioning robots vs. strategy is robust to robot error
- Manipulation technique: **pushing, caging, towing, grasping**

Some Prior Work on Collective Transport

Berman et al., *Proceedings of the IEEE*, 2011

- Many approaches rely on centralized or leader/follower schemes [Montemayor and Wen, ICRA 2005]

  - Require knowledge of load geometry and possibly the contact forces

- Decentralized schemes have been developed for motion and force control of a payload

  [Bai and Wen, ACC 2009; Khatib et al. 1996; Liu et al. 1997; Montemayor and Wen, ICRA 2005; Su and Krovi DSCC 2008; Sun and Mills 2002]

  - Fixed group of robots

  - No obstacles

  - Experimentally verified with 2 robots

Manipulation Technique: Pushing

Kube and Bonabeau, *Robot. Auton. Sys.* 2000

Robots switch between simple behaviors in response to locally sensed cues

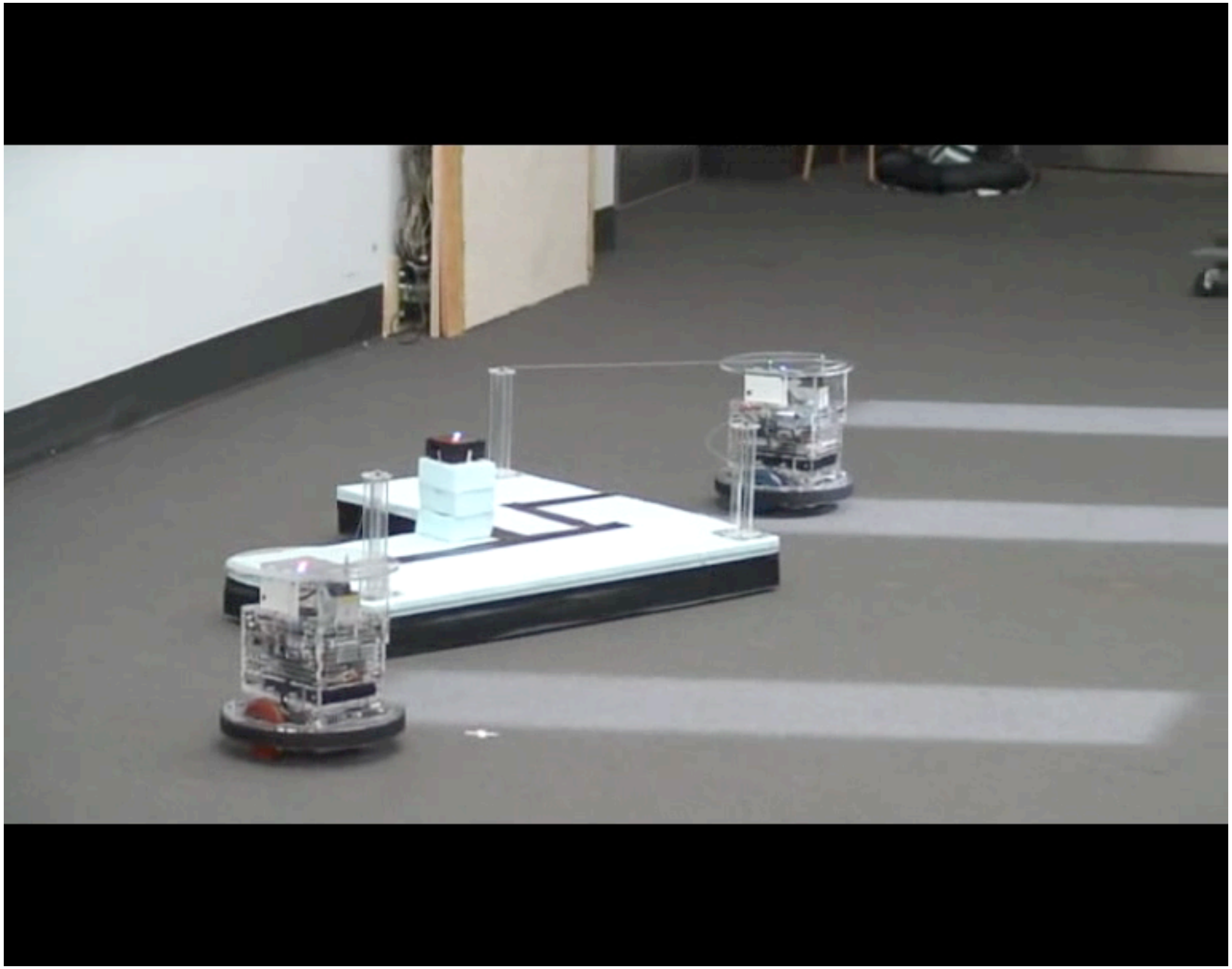
Manipulation Technique: Caging

Jon Fink et al., *RSS'07, ICRA'08*

Geometrically enclose and move an object in a predictable manner

Manipulation Technique: Towing

Peng Cheng et al., *ASME J. Mechanisms & Robotics* 2009



Manipulation Technique: Grasping + Dragging

Quentin Lindsey et al., *ASME IDETC/CIE* 2010

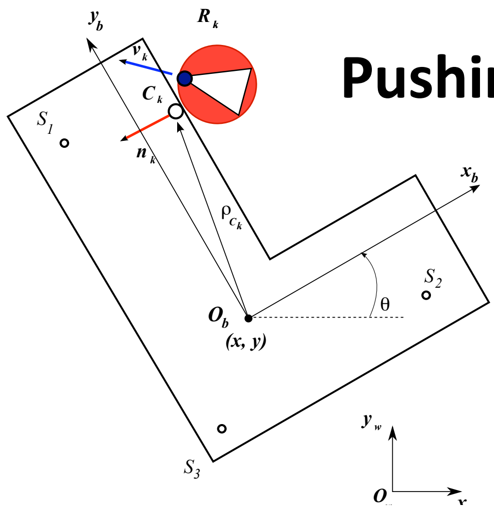
Predict the payload motion using dynamic models that incorporate friction

Model for Manipulation by Grasping

Quasi-static: Inertial forces << Friction forces

Model friction using finite support point approach

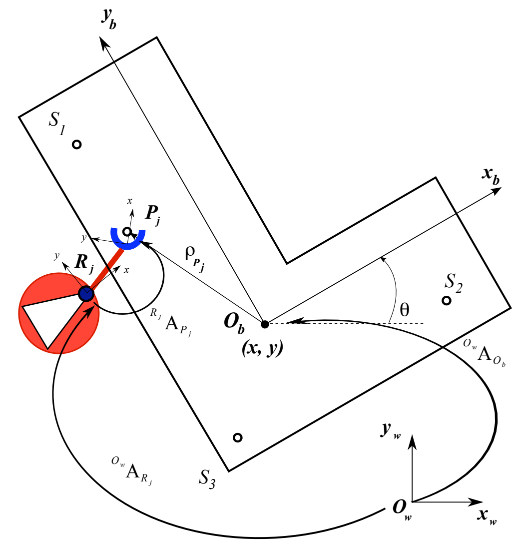
[Cheng et al., ASME J. Mechanisms & Robotics '09]



Pushing Model

+

Gripper Model



$$\xi_{obj} = \begin{bmatrix} \dot{x} & \dot{y} & \dot{\theta} \end{bmatrix}^T$$

Instantaneous power

$$L(\xi, \lambda_t) = \xi_{obj}^T B^T \lambda_t + \Sigma_j^m \xi_{E,j}^T \mathbf{w}_j$$

Due to friction   Due to elastic deformations

$$\underset{\xi_{obj} \in \Sigma}{\text{maximize}} \ \underset{\lambda_{t,i} \in \mathcal{FC}_i}{\text{minimize}} \ L(\xi, \lambda_t)$$

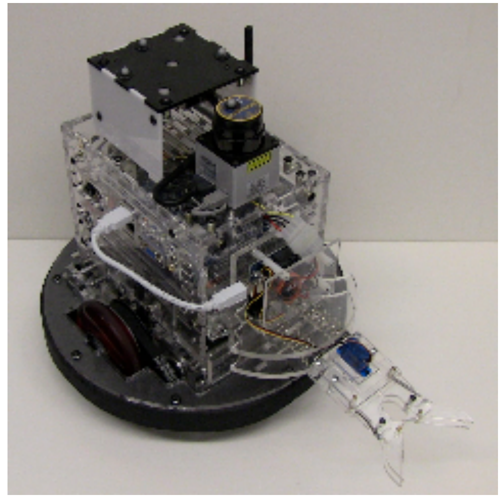
$\lambda_t =$ Friction forces at S_i

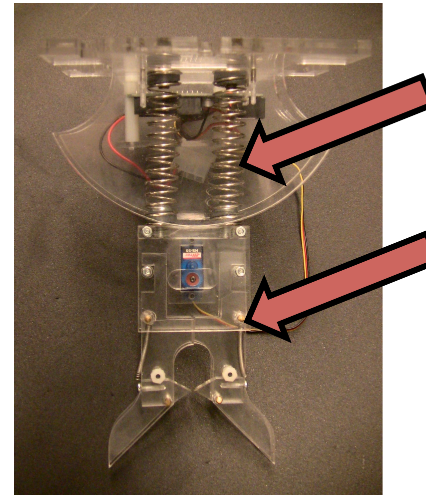
$\mathbf{w}_j =$ Wrench caused by deformation of spring j

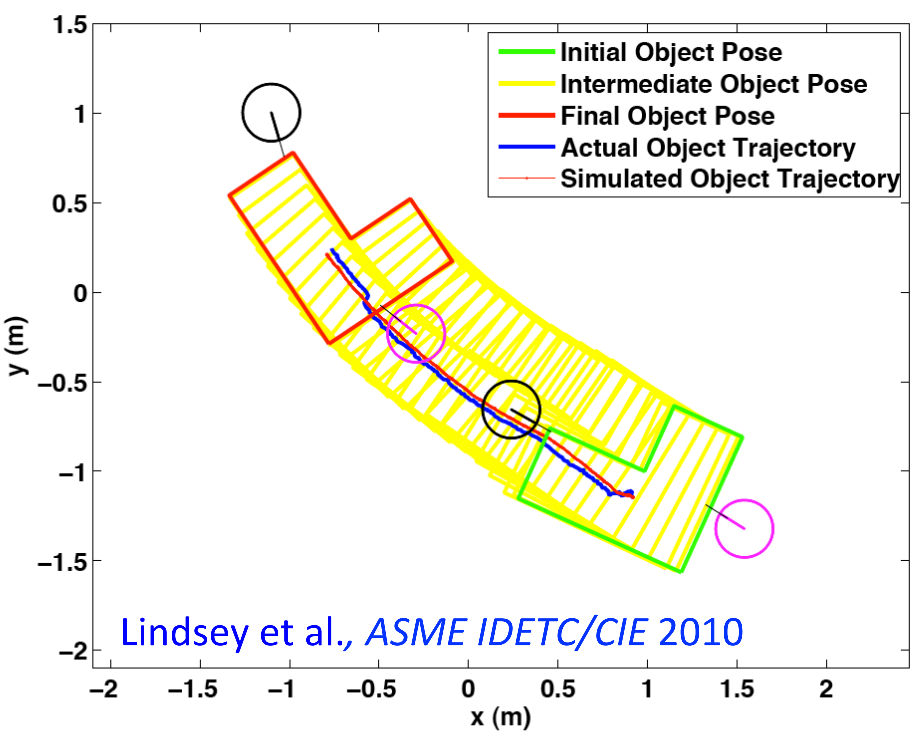
Multi-Robot Grasping Experiments

- SCARAB robots
- VICON motion tracking system
- MATLAB software interfacing to robots through Player

[Gerkey et al., ICAR'03]

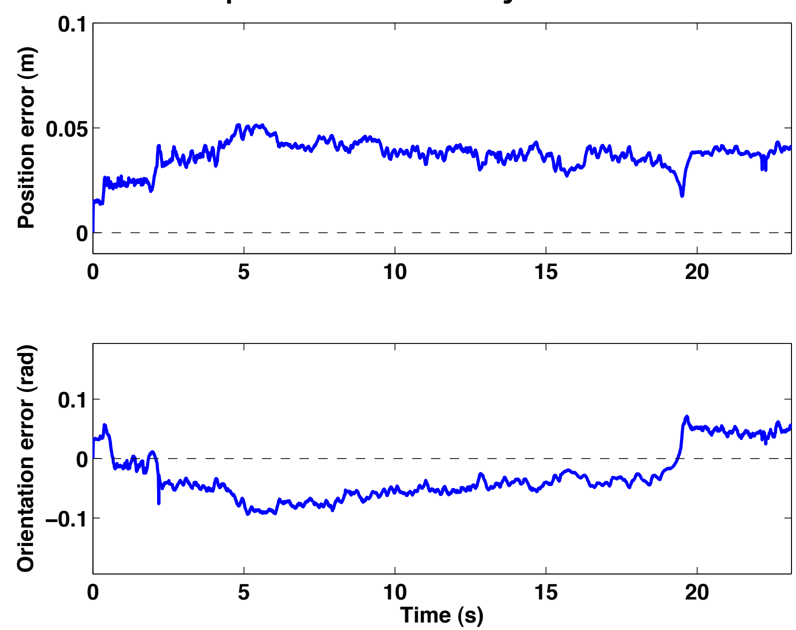






Lindsey et al., *ASME IDETC/CIE* 2010

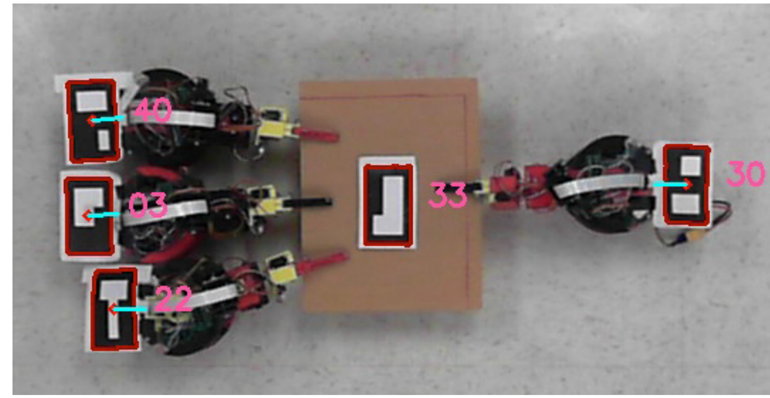
Error between simulated and experimental trajectories



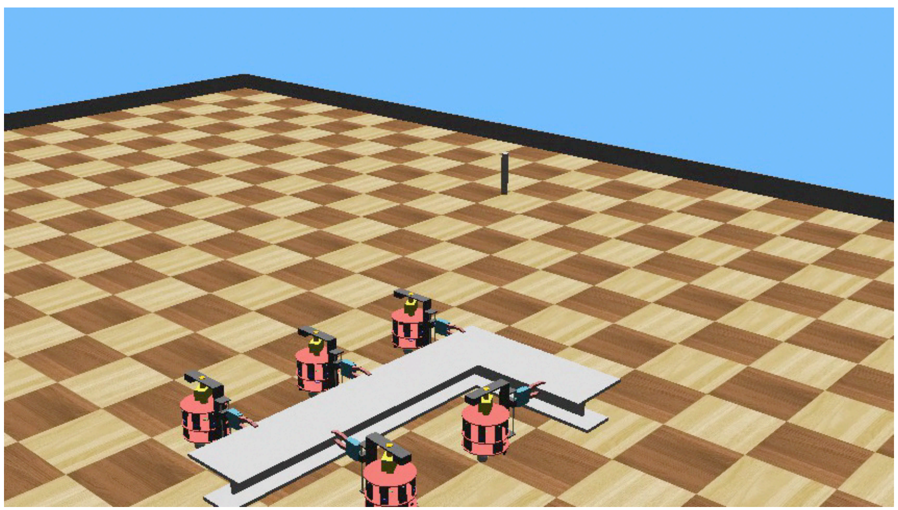
Manipulation Technique: Grasping + Lifting

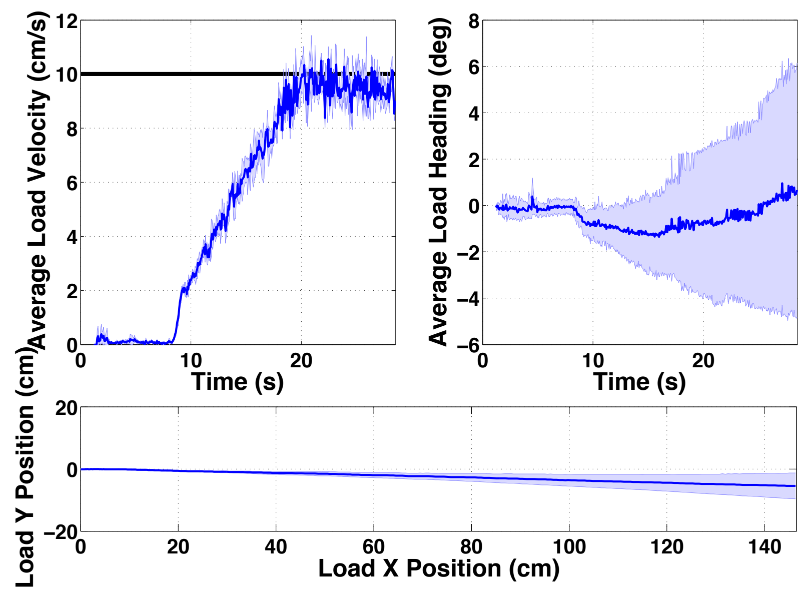
Farivarnejad, Wilson, and Berman, *CDC* 2016

Decentralized control approach using sliding mode control



Webots multi-robot simulator





Collective Transport by Robotic Swarms

Sean Wilson et al., *Swarm Intelligence* 2014

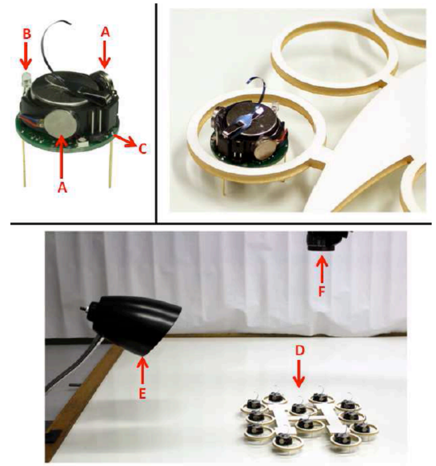
Control strategies have been recently developed with one or more of these properties:

- Are derived from a dynamical model of the system, enabling theoretical analysis of the transport behavior
- Allow robots to detach from the payload, dynamically allocating themselves to the transport team
- Do not require a centralized controller for any information other than high-level task specifications
  (ex. types of payloads to be retrieved)

Collective Transport of Complex Objects by Simple Robots

Mike Rubenstein et al., *AAMAS* 2013

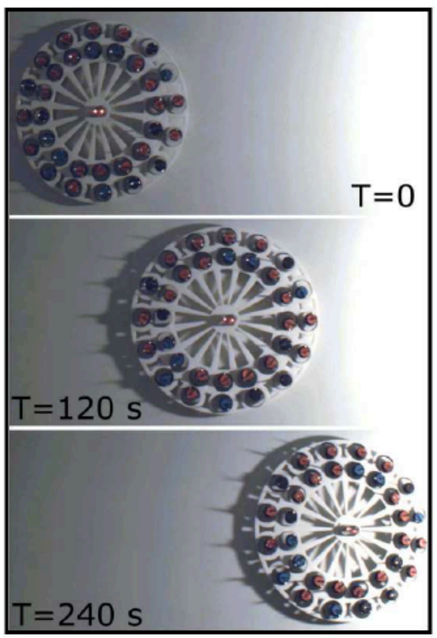
Kilobot robot

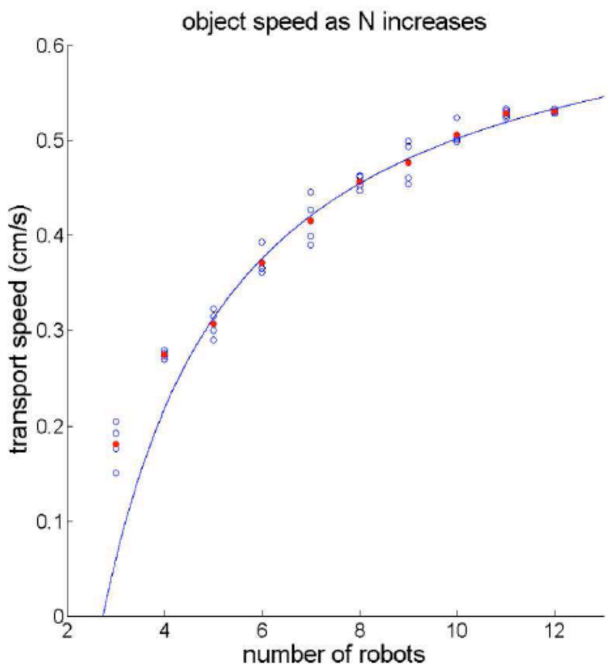


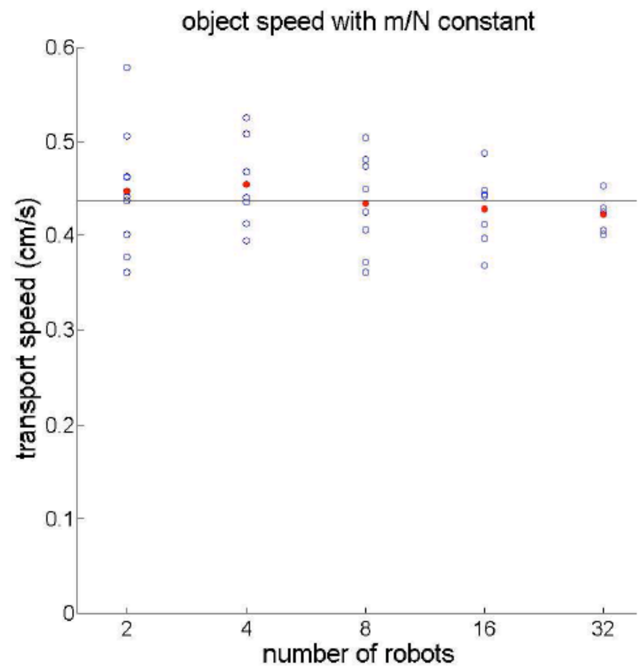
Derive and experimentally validate a physics-based model for transport of arbitrarily shaped rigid objects by a fixed group of robots

- Show that load rotation is transient and <= 180 deg

Video: https://www.youtube.com/watch?v=qAjWL6AyIeE



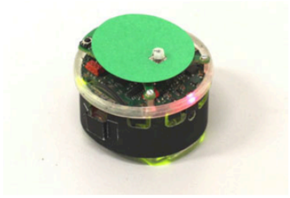




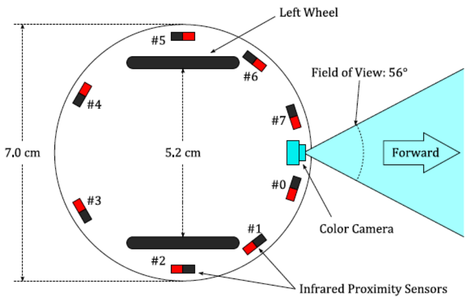
Occlusion-Based Cooperative Transport with a Swarm

Jianing Chen et al., *IEEE Transactions on Robotics* 2015

e-puck robot



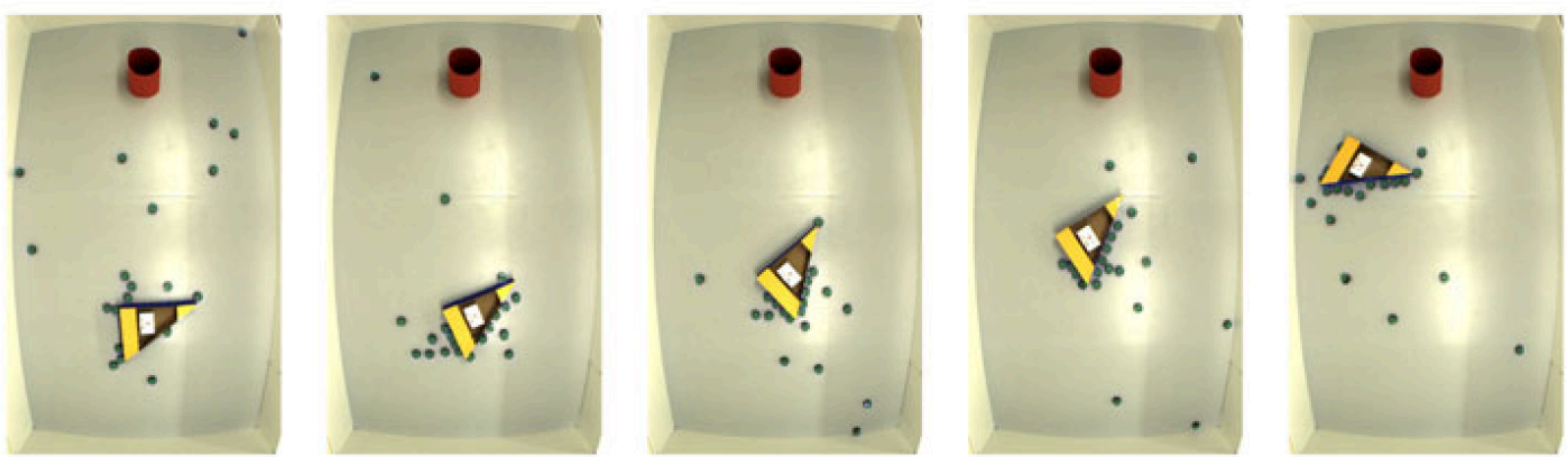
(a)



(b)

Organize a set of pushing robots behind a tall object by exploiting the object's visual obstruction of a destination marker

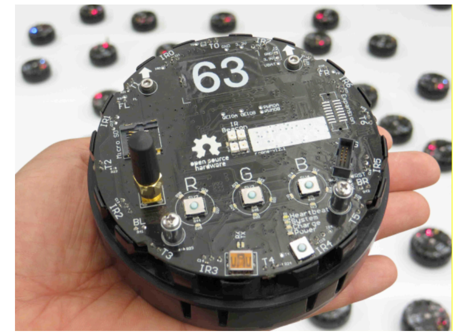
Videos:
http://naturalrobotics.group.shef.ac.uk/supp/2014-002/



Controlling Large Populations with a Single Input Signal

Aaron Becker et al., *IROS* 2013

r-one robot



Use a broadcast control input to steer the swarm around the environment and push an object encountered by the mass of robots to a target configuration

Video:
https://www.youtube.com/watch?v=qIW6hPgqCRE