LEADER FOLLOWER CONTROL OF MULTI-ROBOT FORMATIONS

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MOTIVATION

- Animals often swarm together to cooperate in achieving a collective goal. Members of a swarm follow a leader to maintain a locally rigid formation. Similarly, robots can emulate this herding instinct to perform large-scale tasks, which would be impossible to complete independently.

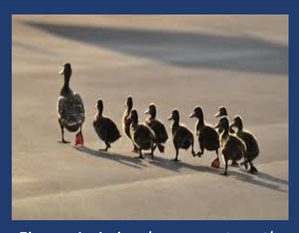


Figure 1: Animals swarm together

- A *multi-robot formation* can be used to accomplish tasks that require physical coordination between individual agents. For example, robot swarms can transport large objects or help with search and rescue missions in dangerous conditions.

Figure 2: A formation of quadrotors

RIGIDITY THEORY

BAR AND JOINT FRAMEWORK

- **Laman’s Theorem:** *A graph is generically, minimally rigid in 2D if and only if it has* 2n −3 *edges and no subgraph of* k *vertices has more than* 2k −3 *edges.*

Flexible Structure:

Rigid Structure:

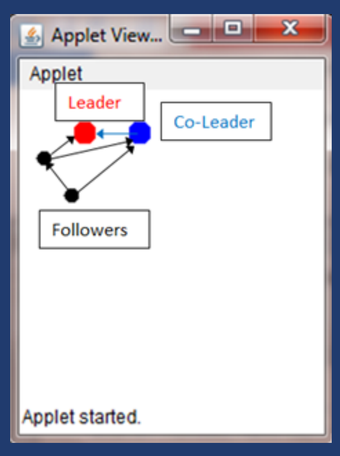
- **Minimally rigid graphs** optimize the number of connections between joints in a rigid graph.
- **Persistent (directed) graphs** minimize communication cost.

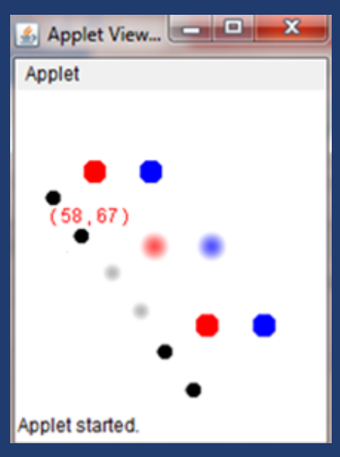
Rigid, but not minimally rigid | **Minimally rigid** | **Persistent (directed)**

2D SIMULATION

An interactive Java simulation program represents the synchronized movement of multiple agents in 2D to maintain a **persistent formation**.

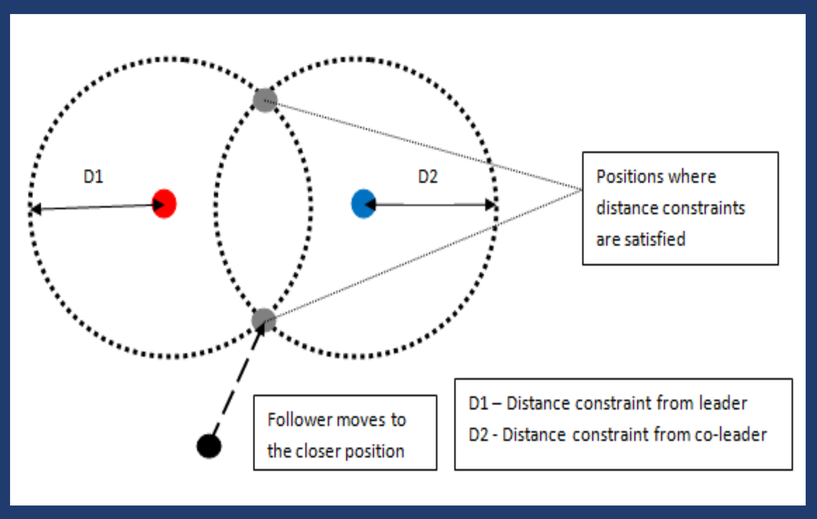
This formation is based on a **rigid** *bar-and-joint* framework, and its persistence is maintained by satisfying directed *point-to-point distance* constraints between the nodes in a graph [3].





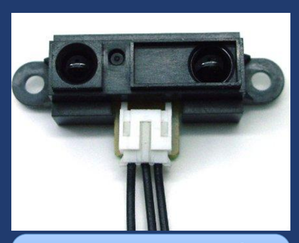
Each robot can follow up to two other robots.

To compute the position for a follower, we find the intersection of two circles, whose radii are defined by the distance constraints of each leader.

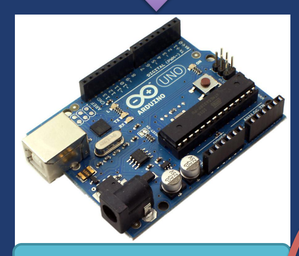


The leader can be dragged freely to any position on the plane. The other agents in the formation rearrange themselves to a new position, where the *distance constraints* are satisfied.

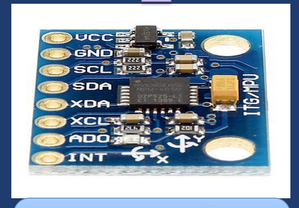
HARDWARE PROTOTYPE



IR Distance Sensor[3]
Measures the leader’s distance from followerz

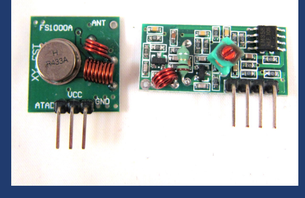


Arduino Uno[4] (Leader)



Tilt Sensor [5]
Senses the leader’s own orientation in space.

Radio Frequency Transmitter & Receiver [6]



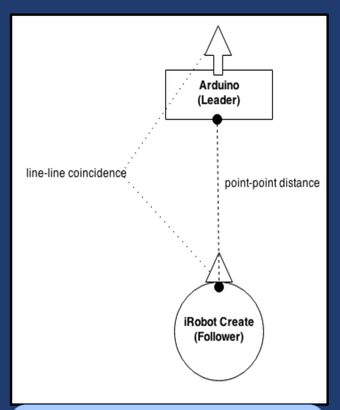
Infrared Communication [7]

Our *body-and-cad* system is based on rigid bodies with specific coincidence, *a*ngular and *d*istance constraints [2].

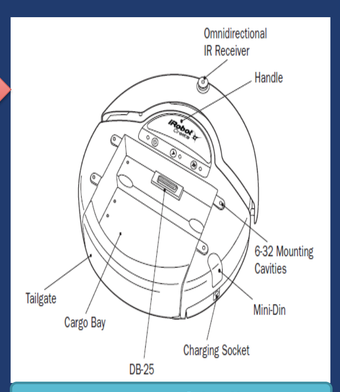
The *leader - follower formation* maintains:

- *Point-point distance* using a distance sensor
- Initial setup for *line-line coincidence* using a tilt sensor

Leader (*Arduino*) instructs the follower (*iRobot Create*) to move or turn accordingly by emitting RF signals. Internal communication in the iRobot Create is done via IR signals.



Constraints maintained between Leader and Follower



iRobot Create [8] (Follower)

FUTURE WORK

- Develop persistence theory for body-and-cad structures.
- Create simulation software to investigate the behavior of body-and-cad leader-follower formations.
- Apply theory to implement an approach for simultaneously maintaining angular and distance constraints between a leader and follower, as outlined in Figure 4.
- Expand the hardware formation from two agents to four or more agents.

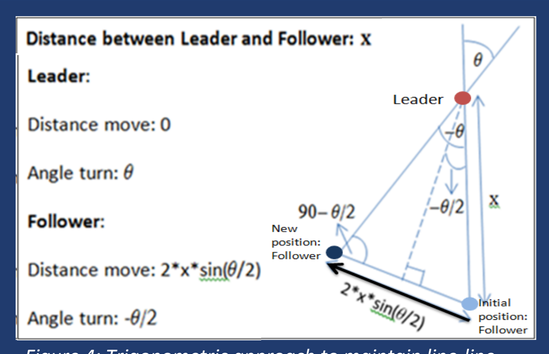
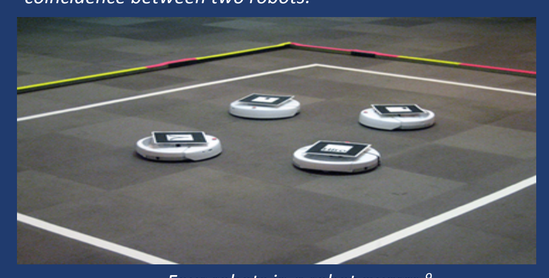


Figure 4: Trigonometric approach to maintain line-line coincidence between two robots.



Four robots in a robot swarm [9]

ACKNOWLEDGEMENTS

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[1] Jack Graver, Brigitte Servatius, and Herman Servatius, *Combinatorial rigidity* (James E. Humphreys, Robion C.Kirby, and Lance Small, eds.), Graduate Studies in Mathematics, vol. 2, American Mathematical Society, 1993.

[2] Kirk Haller, Audrey Lee-St. John, Meera Sitharam, Ileana Streinu, and Neil White, *Body-and-cad geometric constraint systems*, Computational Geometry: Theory and Applications, 45 (2012), no. 8, 385-405.

[3] Julien M. Hendrickx, Brian D. O. Anderson, and Vincent D. Blondel, *Rigidity and persistence of directed graphs*, In proceedings of the 44th IEEE conference on decision and control, 2005, pp. 2176-2181.

Image Citations:

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[2] http://www.seas.upenn.edu/~dmel/mellingerDARS10.pdf
[3] http://www.australianrobotics.com.au/products/sharp-gp2y0a21yk0f-analog-distance-sensor-10-80cm
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