A Distributed Thermodynamics-Inspired Approach to Multi-Robot Obstacle Avoidance

USC University of Southern California

The Interaction Lab

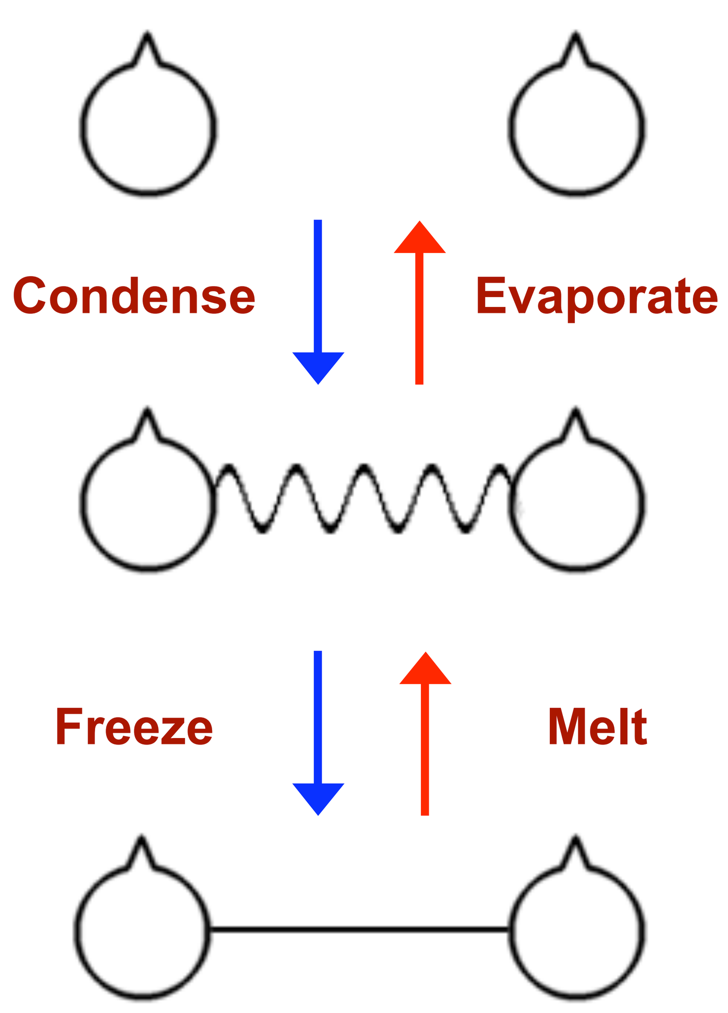
Cauchy Choi – cauchych@usc.edu
John O'Hollaren – ohollare@usc.edu
Ross Mead – rossmead@usc.edu
Maja J Matarić – mataric@usc.edu

Objectives

- Get a number of robots into a specified spatial organization and handle real-world events that could disrupt the formation [1].
- Develop an obstacle avoidance method capable of maintaining rigid multi-robot formations through complex environments.
- Use principles of thermodynamics in a group-level obstacle avoidance algorithm.

Approach and Methods

Our approach focuses on obstacle avoidance and maintenance of formations. The obstacle avoidance scheme draws from the principles of thermodynamic phase transitions. We refer to the transformation from a multi-robot swarm to a rigid formation as a "phase transition", since it has many parallels to the state phase transitions observed in matter.



Gaseous State: a group of mobile robots with no particular programming for interaction with each other, aside from individual collision avoidance

Liquid State: robots in a swarm—the swarm is free to assume the shape of its surroundings, but maintains a fixed volume

Solid State: robots in formation, maintaining both a fixed volume and shape

Why Robot Formations?

Multi-Agent Coordination

- Teams of autonomous vehicles, ranging from automobiles to aircraft, can apply the method to navigation.
- A cost-effective platform on which to test multi-robot deployment schemes will allow more thorough testing on physical robots in lieu of simulators.

Societal Relevance

- Efficient planting and maintaining of uniform rows of crops [1].
- Coordinating large grid formations of robots has been suggested for the "volumetric control" (surveying or monitoring) of some environment [2].
- Creating and maintaining a Space-Based Solar Power reflector or collector to help meet the world's future energy needs [1, 3].
- Recent applications for highway traffic control and safety are also being explored [4].

Equations and Notation

- From the equation for thermodynamic calorimetry:

$$Q = mC\Delta T$$

- We extend the temperature equation:

$$T_i^{t+1} = \frac{\sum_{j=1}^{n} Q_j^t + mCT_i^t}{mC}$$

where

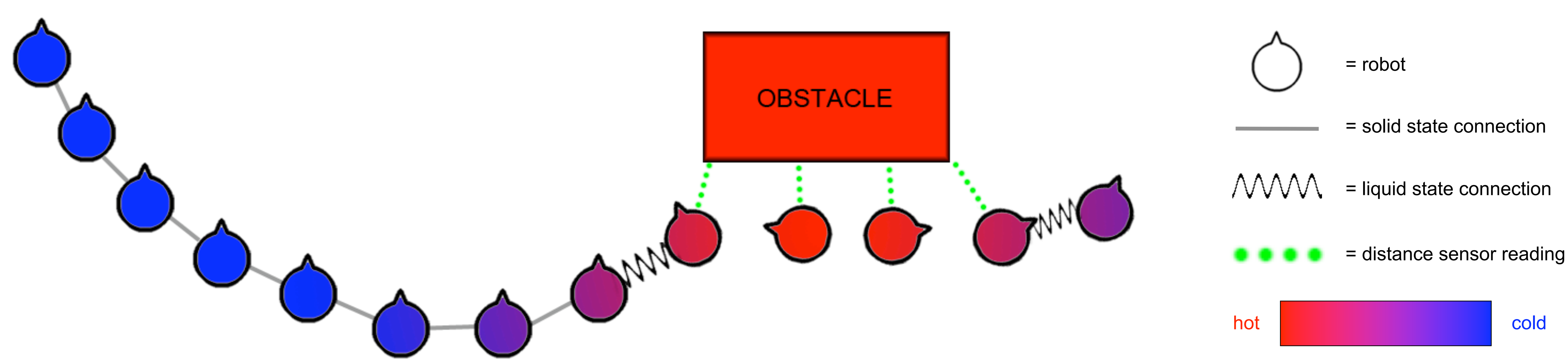
$$Q_j^t = \frac{\kappa A(T_j^t - T_i^t)}{d_j^t}$$

Q = heat transferred between robots
m = mass of one robot
C = specific heat *
T = temperature of the current robot
t = current time step
i = current robot index
j = neighboring robot index
n = number of neighboring robots
κ = conductivity constant *
A = surface area of connection
d = distance between robots

* = determined empirically

from the equation for the heat transfer via cylindrical conduction.

- These equations are used to update the internal "temperature" of each robot.
- Temperature is affected primarily by obstacles, and is propagated to neighboring robots via wireless communication.



Representation of the "temperature" of each robot as a function of its distance to an obstacle and the "heat" transferred from neighboring robots.

Phase Transition Obstacle Avoidance

- As robots on the perimeter of a rigid, "solid" formation encounter an obstacle, they "warm up" and transition to a "liquid" phase. The liquid (or less constrained) section of the robotic swarm can then circumvent the obstacle.
- Once the obstacle becomes farther away, the robots "cool down" and return to their solid form. In this manner, the robotic formation is capable of navigating a wide variety of obstacles.
- If the robot is far too close to an obstacle, it transitions into the "gas" phase and ignores all spatial relationships, treating other robots as obstacles as well. The robot can then transition back into the "liquid" and eventually "solid" phase as it cools down.
- Once the robot determines itself to have passed the influence of the obstacle, it reestablishes its temporarily ignored spatial relationships.

Discussion and Future Work

- This method demonstrates the feasibility of using thermodynamic principles and innovative programming techniques to properly maintain and structure robots in complex environments.
- Future work will implement the algorithm on a number of iRobot Creates to establish a formation of robots that interact with each other and participate in obstacle avoidance based on these thermodynamic principles.
- The long-term objective of this research is to see if a thermodynamic-inspired approach to obstacle avoidance is a viable solution in the real-world multi-robot systems.

Acknowledgments

This work is supported by the Undergraduate Research Associates Program (URAP) and the USC Interaction Lab under the direction of Maja J Matarić and Ross Mead. We would like to thank Gavin McCarter for his assistance in extending the heat transfer equations to the distributed robot network.

Selected References

[1] R. Mead, "Cellular Automata For Control and Interactions of Large Formations of Robots, "*Master's Thesis – Southern Illinois University Edwardsville*, 2008, <http://robotics.usc.edu/~rossmead/docs/2008/2008Mead_Thesis.pdf>.
[2] W. Spears, D. Spears, J.C. Hamann, R. Heil, (2004) "Distributed, physics-based control of swarms of vehicles," *Autonomous Robots*, vol. 17, 2004, pp. 137-162.
[3] G. Bekey, I. Bekey, D. Criswell, G. Friedman, D. Greenwood, D. Miller, and P. Will, *Final Report of the NSF-NASA Workshop on Autonomous Construction and Manufacturing for Space Electrical Power Systems*, April 4-7, 2000, Arlington, Virginia.
[4] S.M. Farritor and S. Goddard, "Intelligent highway safety markers," IEEE Intelligent Systems, vol. 19, no. 6, 2004, pp. 8-11
[5] Holman, J.P. *Heat Transfer*. 10th ed. New York: McGraw-Hill, 2009. pp. 27-60. Print.