Prelim Notes

## Organization

### **Introduction**

1. Quick intro to the field of swarm robotics☒
2. The goal of this survey paper☒
3. Motivation behind research in this field and real-world applications ☒
   1. Inspired from biological systems
   2. Advantages to using swarm robots instead of larger robots
      1. Reliability
      2. Scalability
      3. Low design and maintenance cost (easily replicable)
4. Why do we model these systems? ☒
   1. Modeling provides a mathematically sound process to predict the behavior of the system as well as optimize system parameters to expose the properties that are most desirable in the swarm ☒
   2. Physics based simulators take time to develop and use. Simulations are generally faster than physical experiments but slower than mathematical model solvers. They are also not exact (by their very nature) and therefore could miss emergent behavior or other macroscopic properties of the system ☒
   3. Physical experiments require expensive hardware and are time consuming. No reliable, large-scale, physical implementation of swarm robots. It is also difficult to observe and measure large scale system properties without the use of more sophisticated tools like machine vision and global communication ☒
5. Explain layout of the rest of the paper ☒

### **Terms and Definitions**

1. Robot/Agent ☐
2. Swarm System ☐
3. Macroscopic Model ☐
4. Microscopic Model ☐
5. Non-Spatial Model ☐
6. Spatial Model ☐

### **Recipe for Designing a Robot Controller**

1. Create a construct --- generally a flowchart, state-machine or algorithm that describes desired robot behavior.
2. Use this construct to come up with a macroscopic, mathematical description of the system --- generally in the form of a system of ODEs or PDEs
3. Use the same construct to run microscopic simulations of the system using MCMCs or Gillespie simulation, where each agent is simulated individually using dice rolls and probability
4. Use free variables of the system to optimize robot behavior for the required task using the macro-model and verify results with the micro-model
5. Use these parameters in a physics-based simulation of the entire system as well as physical experiments with real robots
6. Use the results of the physical experiments to improve the original construct and repeat

### **Non-Spatial Models**

1. General introduction and history of non-spatial model development ☐
2. Design of construct, i.e. flowchart, FSM ☐
3. Advancing from a deterministic construct (FSM) to a probabilistic one (PFSM) ☐
   1. Go from conditionals to probabilities
   2. Use simple system geometry as well as other environmental and robot parameters to assign probabilities to state transitions
4. Microscopic Model ☐
   1. Gillespie simulation
5. Macroscopic model ☐
   1. ODE system
      1. How is it extruded from the construct?
      2. Explain causes of non-linearity
   2. Mean-Field analysis (Short description) – Should I even include this?

### **Spatial Models**

1. General introduction and history of spatial model development ☐
2. Technique is derived from modeling of Brownian motion in physics and uses the same equations. ☐
3. Microscopic model ☐
   1. Langevin equation
4. Macroscopic model ☐
   1. Fokker-Planck equation

### **Optimization**

1. Non-spatial model optimization of non-linear ODE system ☐
2. Spatial model optimization of PDE system – Is there any work done/literature here?

### **Physical Platforms and Physics-Based Simulators**

1. Present use of physical models in swarm robotics. Talk about Webots. ☐
2. Existing physical platforms --- Khepra, Alice, Kilobots, Disney Display Swarm, Droplets ☐
3. Simulators --- Talk about the physics engines used (Bullet and ODE). Webots, Gazebo, Droplet Simulator ☐
4. Integration between hardware and software --- ROS/Gazebo, Webots, Droplet Simulator ☐

### **Conclusion**

1. Discuss the state of the field so far. ☐
2. The transition from non-spatial to spatial models is important because…? ☐
3. Re-iterate the important aspects of modeling and why swarm robotics is an interesting a growing field. ☐

## Notes

### **Non-Spatial Models**

* Mathematical analysis of multi-agent systems
* Martinoli and Medanda (1995) first stick pulling experiment.
* Martinoli (1999) thesis.
  + No mathematical analysis,
  + Only analyzed results from simulations and real experiment data,
  + Talks about an optimum “timeout” time for robots waiting at sticks.
  + Has graphs that show timeout time based on number of robots and sticks.
  + Uses flowcharts instead of FSM
  + Did not see any difference or differential equations
  + The thesis talks about link between model iterations and experiment time and provides a method for conversion in section 4.2.2

Sections 4.1.2 and 4.2 of Martinoli’s thesis describe the probabilistic modeling methodology for swarm robots. He talks about simulating *probabilistic processes* in parallel, one for each robot. Each process is visualized as a flowchart and is closely related to the robot controller. A distinction should be made between the actual process running on the robot and this simulation process. While the flowcharts look the same, on a robot each edge or state transition in the flowchart is a conditional based on sensory and internal input while the edges of the flowchart in the simulated process are probabilistic and form the basis of the entire modeling methodology: instead of using complex sensory data and internal computation to decide whether a transition should occur in the controller, simple probability and dice rolls are used. The probability of transition on each edge is computed using simple geometric properties of the system, such as ratios of physical sizes, sensor range, etc. Random values are then generated in the simulation to decide the agent’s path of traversal through its flowchart controller. The state of the environment of the swarm system is updated at each time-step through the simulation and stored in a shared memory location.

* Martinoli and Correll (2011)
  + Uses stick aggregation experiment
  + Clear use of state-machine to describe robot behavior
  + Uses difference equations
  + Though the term “Finite State Machine (or PFSM)” is not commonly used in the literature, terms like “State Transition Diagram” tend to define the same concept.
* Lerman (2001) multiple papers
  + First time I see use of differential equations to describe mathematical model for robot behavior
  + In paper, “A General Methodology for Mathematical Analysis of Multi-Agent Systems”, transition from flowchart description to state machine model for robot controller is described.

### **Spatial Models**

Use robot swarms instead of swarm robots in cases where it applies.