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# Application of Swarm Robotics Systems to Marine Environmental Monitoring

Augustine Ekweariri

University of Hamburg
Faculty of Mathematics, Informatics and Natural Sciences
Department of Informatics
Technical Aspects of Multimodal Systems

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# Outline

- Motivation
- Introduction & Fundamentals
- Methodology
- Experimental setup
- Results
- Discussion
- Conclusion

# Motivation

“We know more about the moon surface than the earth’s ocean [1]

- Most talks about climate change is about land
- What about pollution, overfishing, ocean acidification, etc?

Fig 2: ~ 90% of seabirds have eaten plastics in their lives – [3]

Fig 1: The melting Arctic ice cap - [2]

# Motivation Cont.

- Vital in application areas such as
  - Search and rescue
  - Surveillance
  - Clean up
- Few marine vehicles

Fig 3: The Ocean Cleanup organization has a plan to start cleaning it up since march 2018 - [4]

# What is a swarm?

- Group of agents that;
- ….are not centrally controlled
- ….agents are relatively inefficient
- ….have local sensing

- Not all groups are swarm

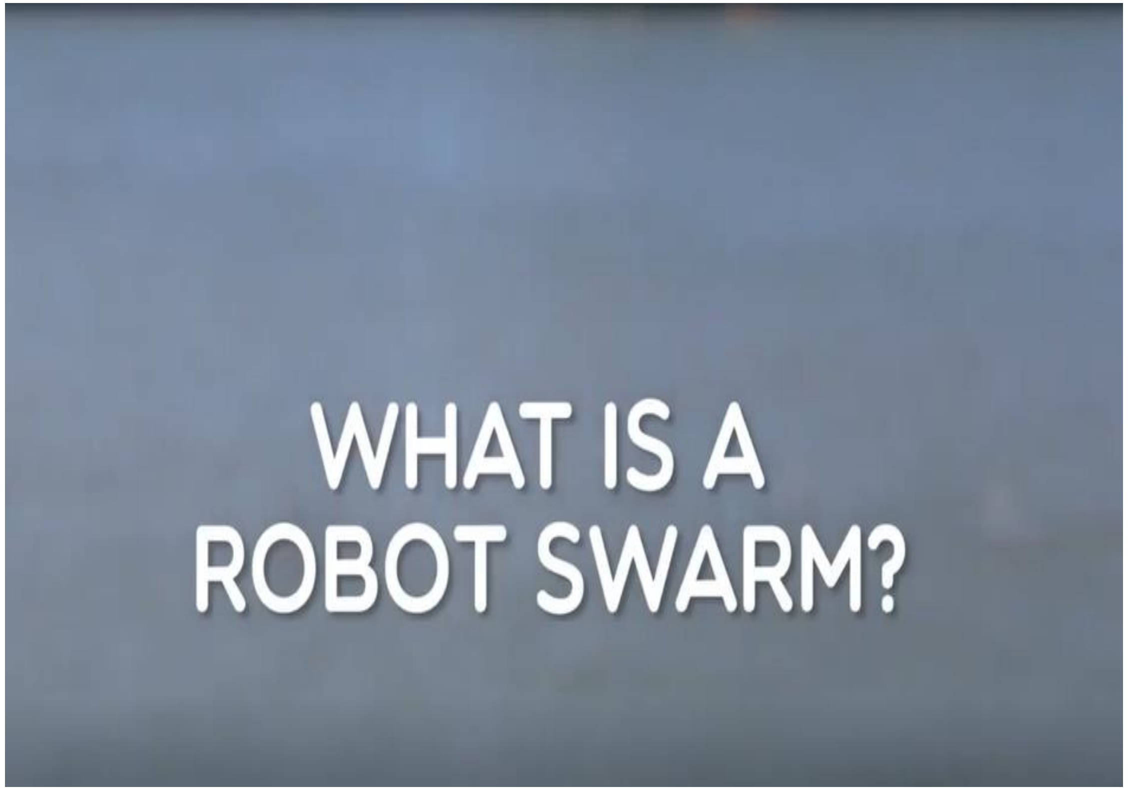



Fig 4: Basics in evolution of collective behavior in swarm robots [6]

# Properties of a Swarm

- Robustness
  - Ability to cope with faults of others
- Versatility
  - Ability to operate in a variety of different environment or assume different task
- Scalability
  - Ability to maintain the group behavior regardless of the swarm size
- Emergent behavior through local interaction

# Aquatic Swarm Robotic System

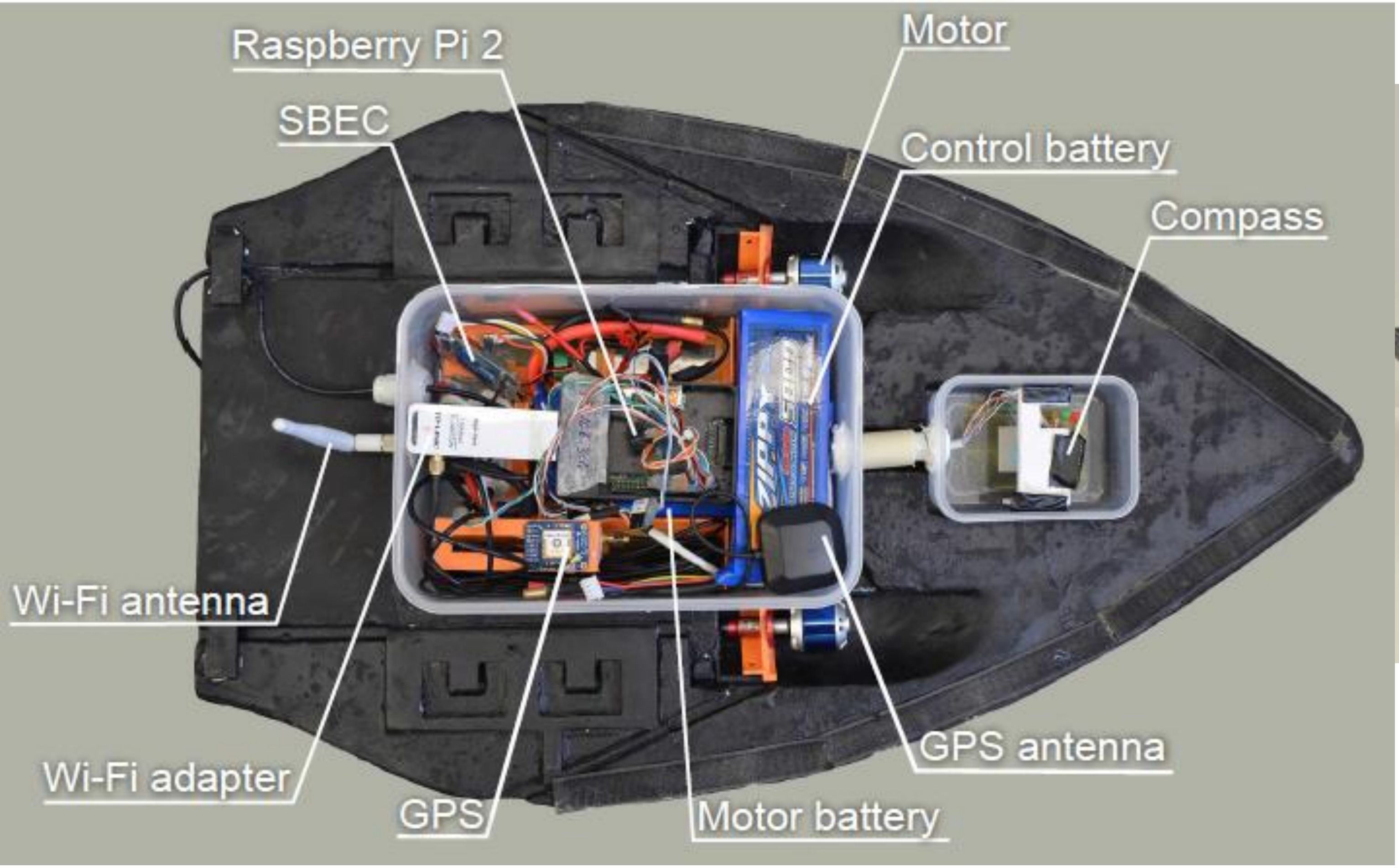
- Advantageous in;
  - Environmental monitoring
  - Marine life localization
  - Sea boarder patrolling

- Why?
  - Distributed sensing
  - High spatial resolution
  - Difficult to carry out with a single or few boats.

# Application of Swarm Robotics Systems to Marine Environmental Monitoring – D. Miguel et al


Fig 5: Eight samples of the out of 10 robots [1]

# Prototype



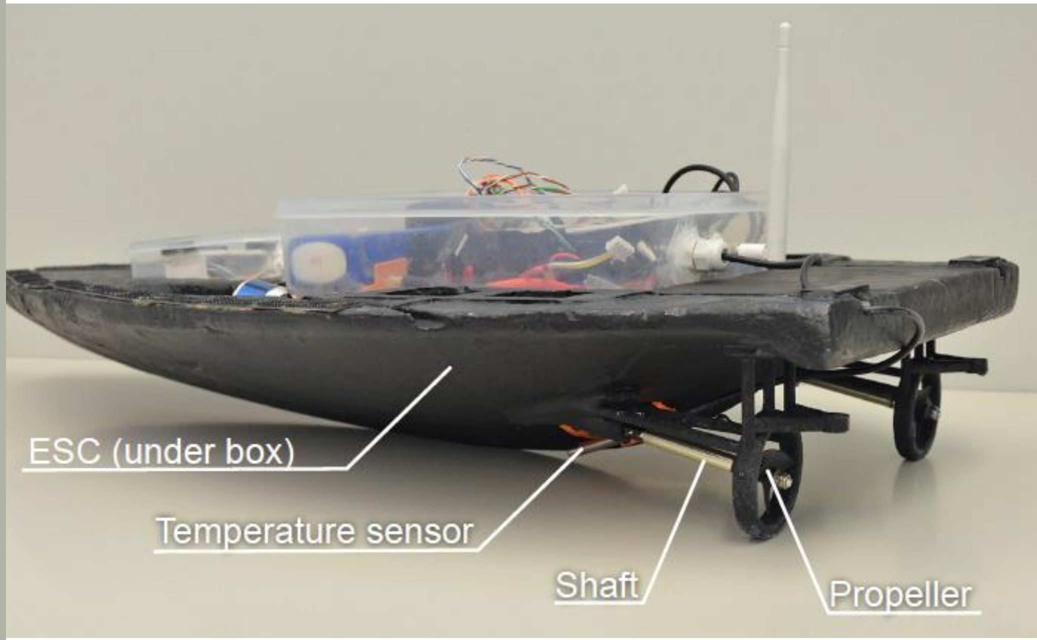




Fig 6: Prototype of the robot – [6]

# Synthesizing the controllers

- Much of a Challenge

**Why?**

- The parameters for local interaction are hard to hardcode.

**Methods**

- Neural Networks
- Reinforcement learning
- Evolutionary computation

# Evolutionary Synthesis of Controller

- Evolutionary Robotics
  - Studies the application of evolutionary computing to synthesis of robot controllers
  - ER is a preferred alternative to manual programming
  - Given a specific task ER algorithm evaluates & optimizes controllers
  - Thereby facilitating the emergence of self organizing behavior

# Behaviors

- The following behaviors should emerge;
  - Homing
    - Navigate to a waypoint without collision
  - Clustering
    - Robots must find each other and form a group
  - Dispersion
    - Robots must get as far away from one another as possible & remain in communication range
  - Monitoring
    - Robots must cover a predefined area

# Methodology

Simulation

- Conducted offline
- JBotEvolver
- Parameters

  = measurement from real robots + noise

- Robot controlled by ANN
  - Input = sensory data
  - Output is speed + heading pos covert to propellers

- Configuration of ANN is optimized by NEAT

# In a nutshell

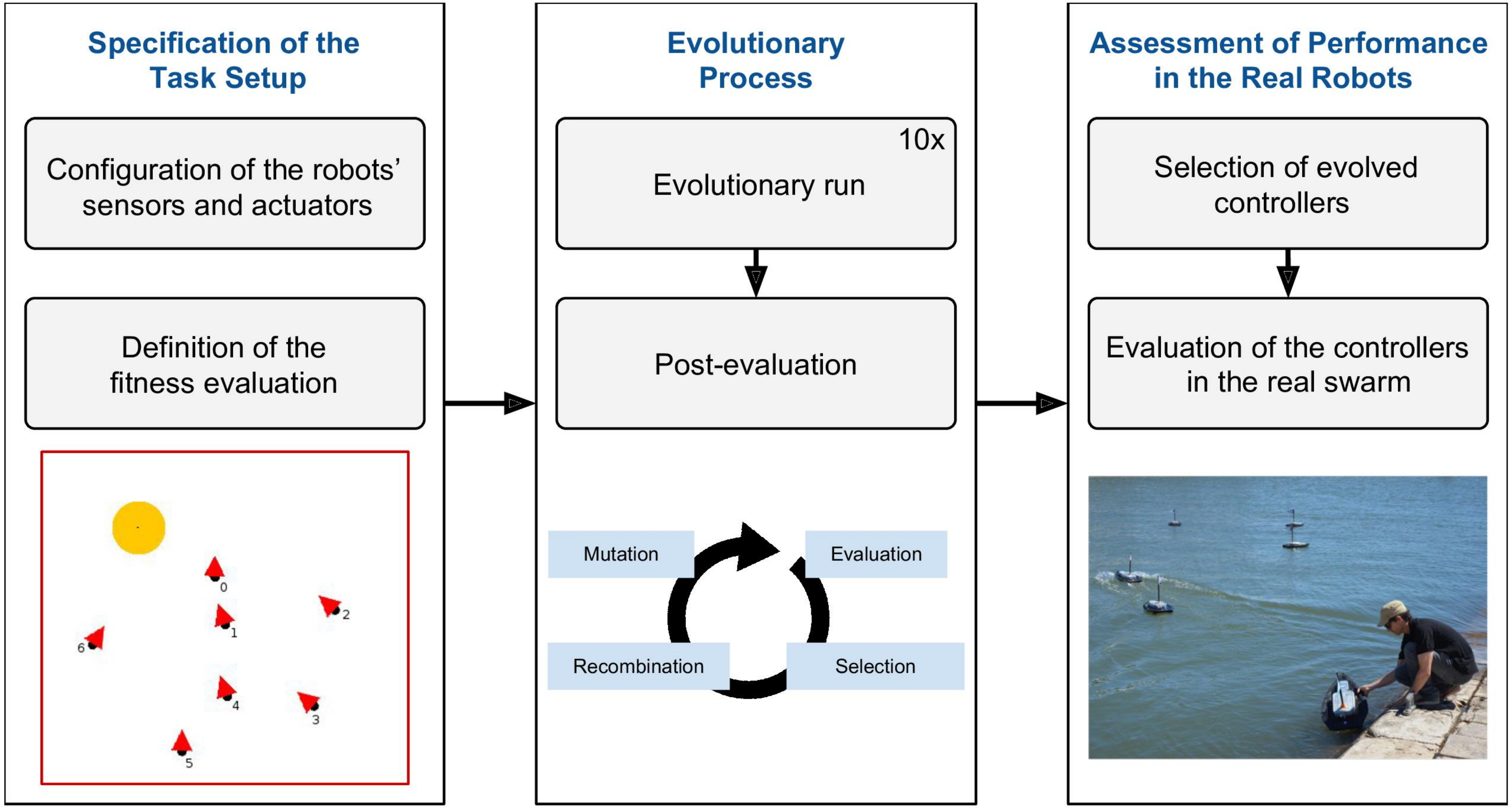



Fig 7: Summary of the process – [6]

# Environmental Monitoring

- Define a geo-fence
- Robots start from base station
- Complete task and return

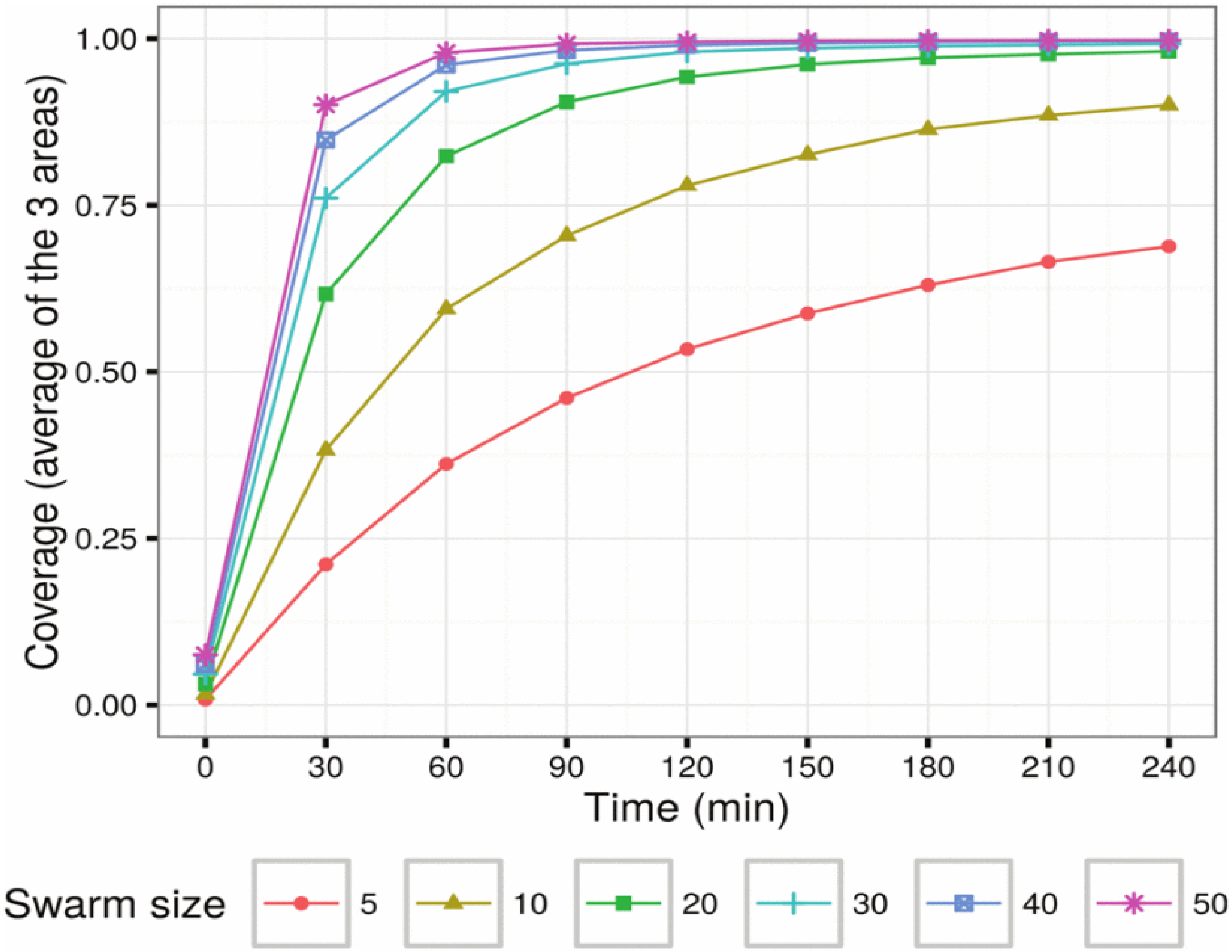
- Area divided into grid cells 100x100m
- Area must be visited by at least one robot

# Experiments - Area of coverage

- Square: A square area with 2.5 km × 2.5 km
- Rectangle: A rectangular area with 4.2 km × 1.5 km
- L-Shape: A square area with 2.9 km × 2.9 km with a cutout of 1.45 km × 1.45 km

- Areas divided into 100 X 100 grid
- grid must be visited at least one robot

# Experiments - Area of coverage cont.




Proportion of the area covered over time, averaged over the three different areas, and ten simulation samples for each area. (Simulation) [1]

Fig 8: Coverage area and heatmap – [1]

# Experiments - Temperature monitoring

Coverage area

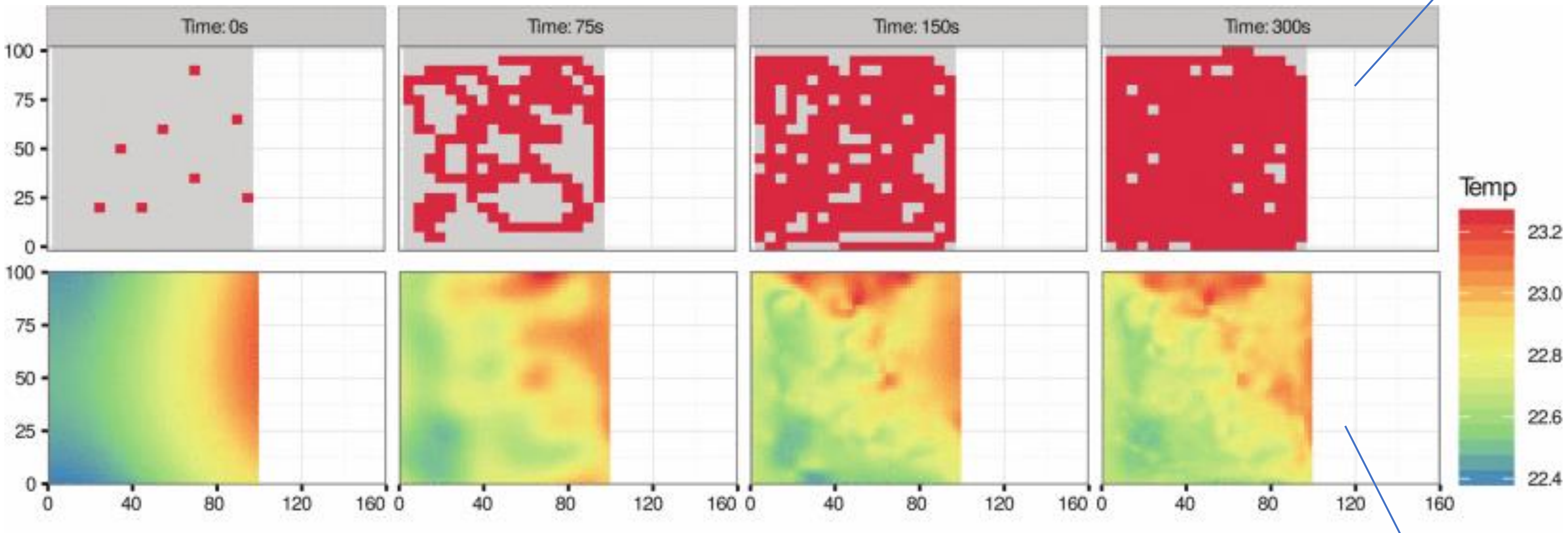



Fig 9: Temperature monitoring and heatmap – [1]

Heat map

# Experiments - Temperature monitoring cont.

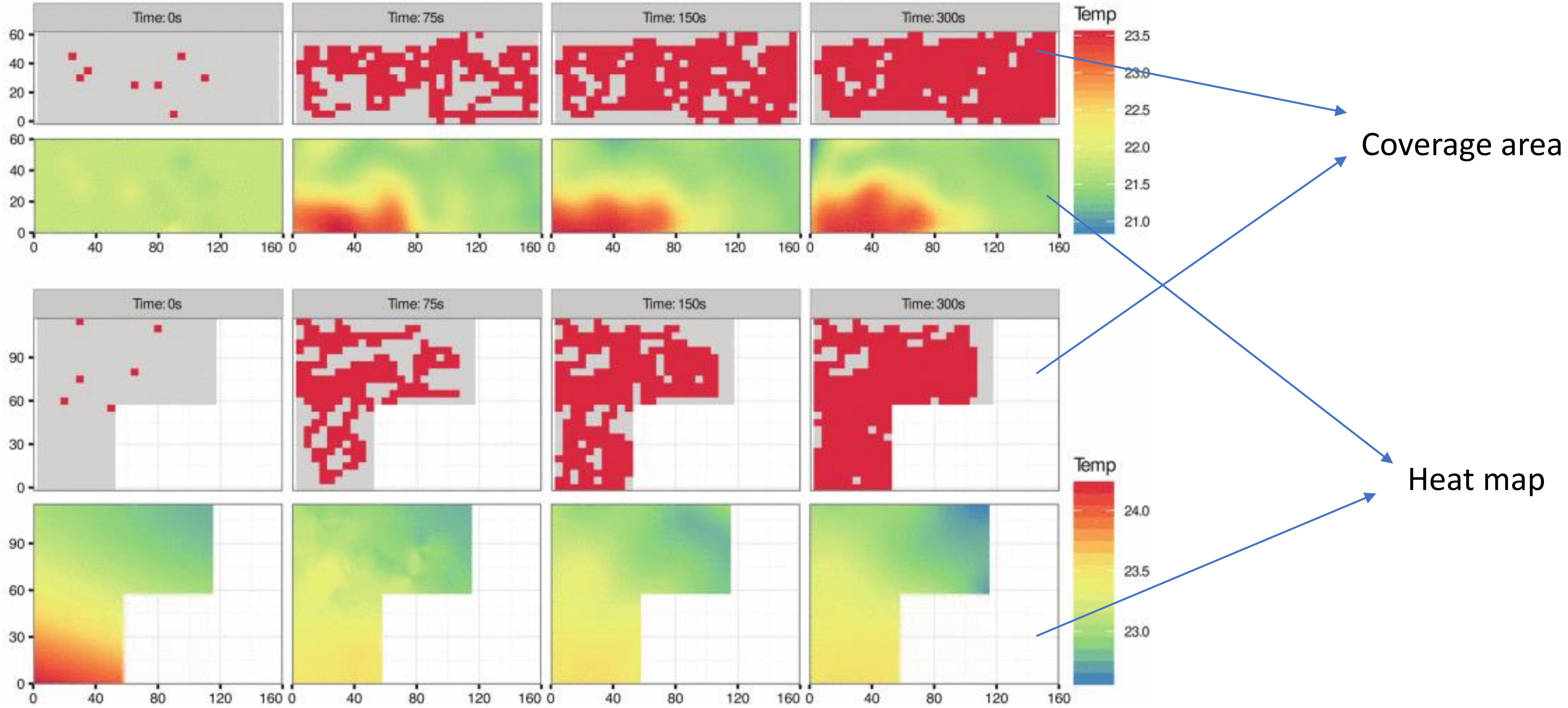
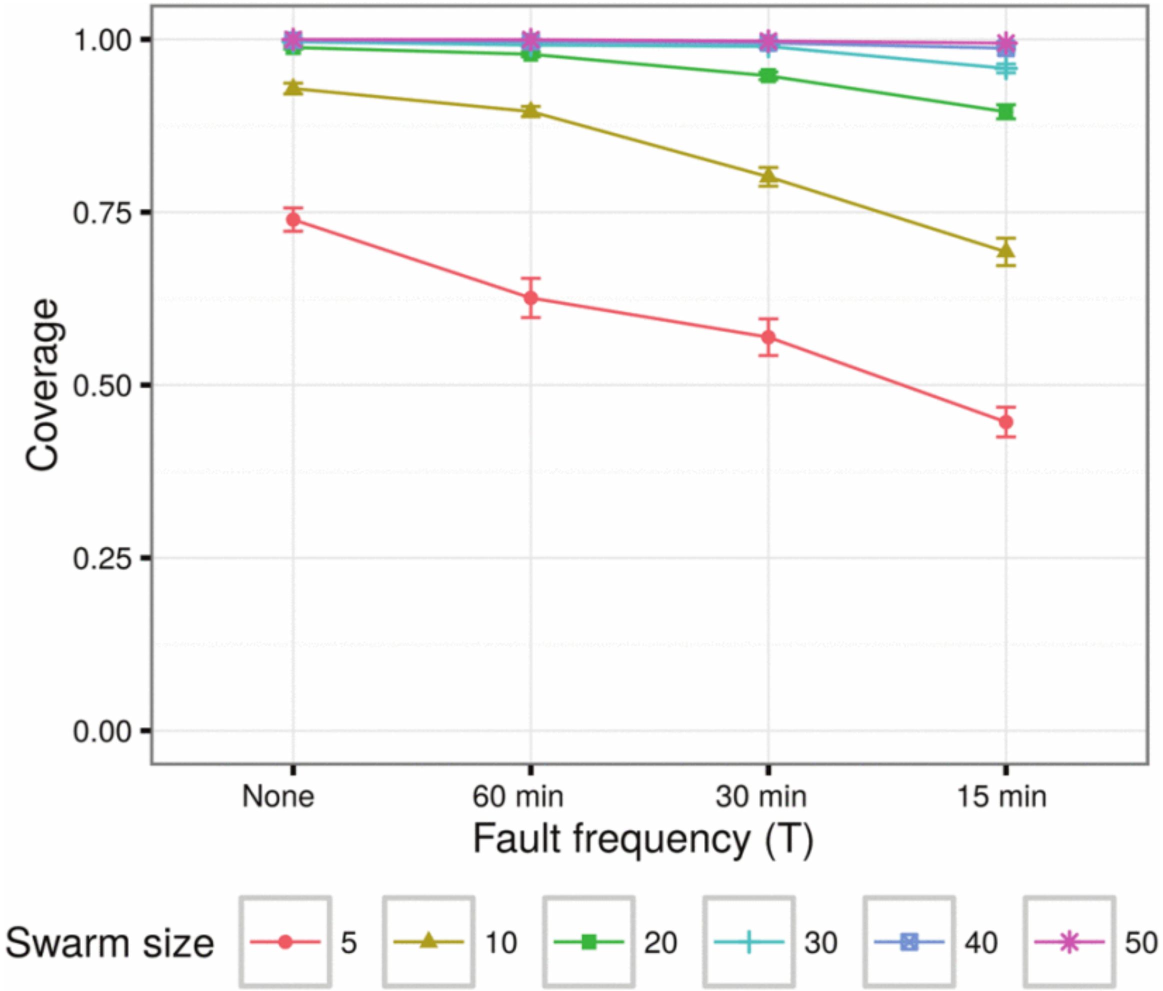



Fig 10: Temperature monitoring and heatmap – [1]

# Experiments – Robustness to fault

- Tested by injecting faults to robots
- Each simulation step, probability of robot failing
- Probability to recover from fault

# Experiments – Robustness to fault cont.

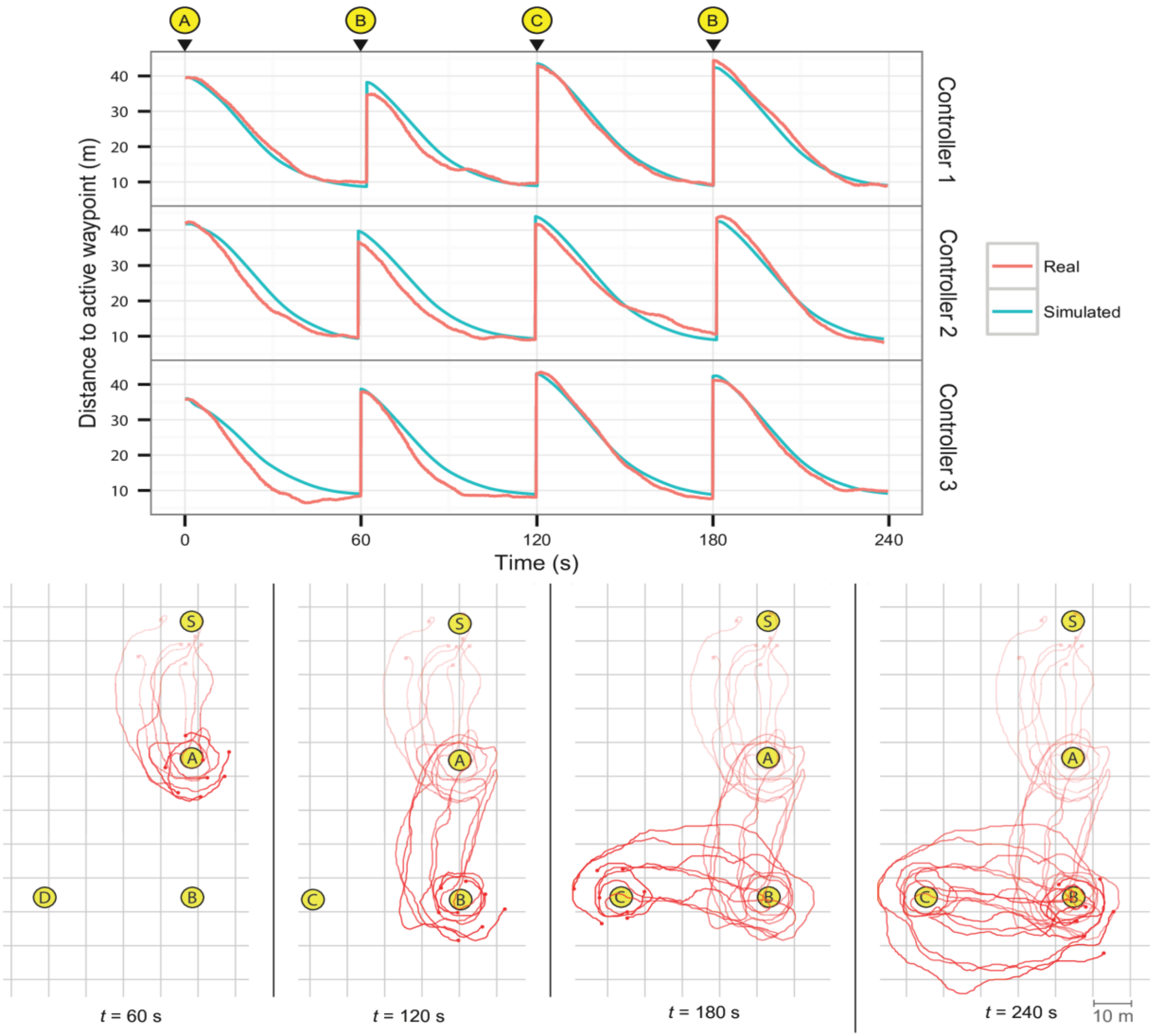



Coverage of the area for a mission time of 240 minutes with temporary faults (simulation) [1]

Fig 11: Robustness to fault – [1]

# Results

- Homing



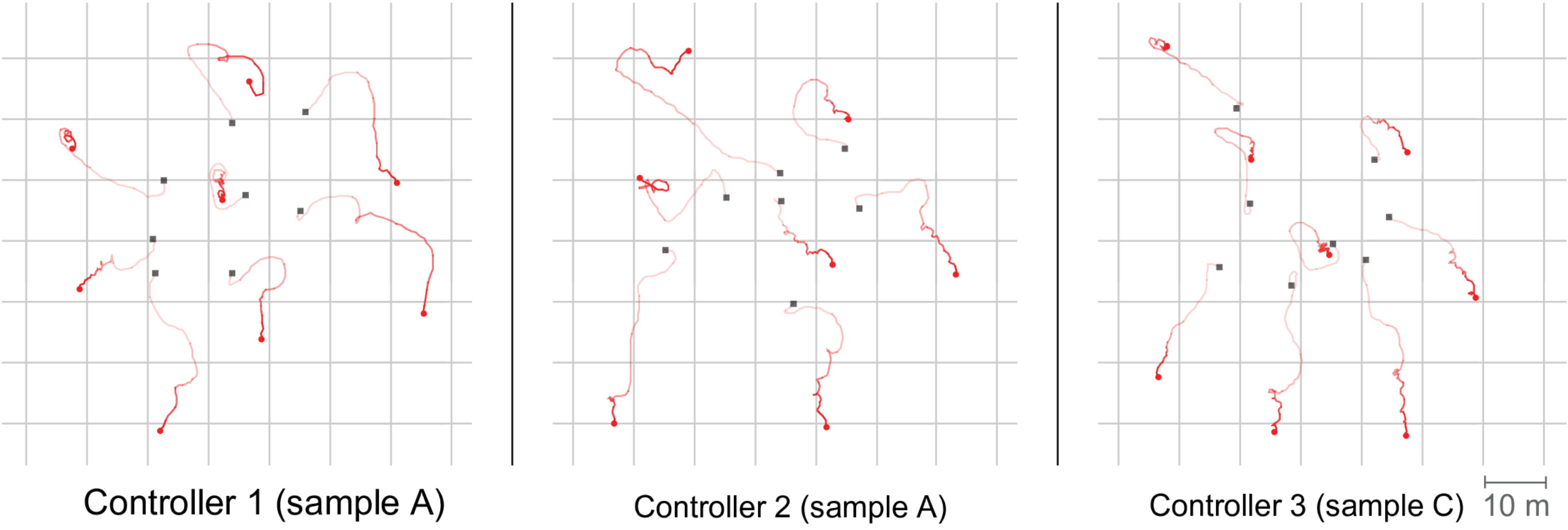

Tested on four waypoints
Waypoints = 40m apart
Time: 4 mins each

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0151834

# Results cont.

- Dispersion

8 robots placed in a cluster
They need to disperse 20m apart
Time: 90 secs each

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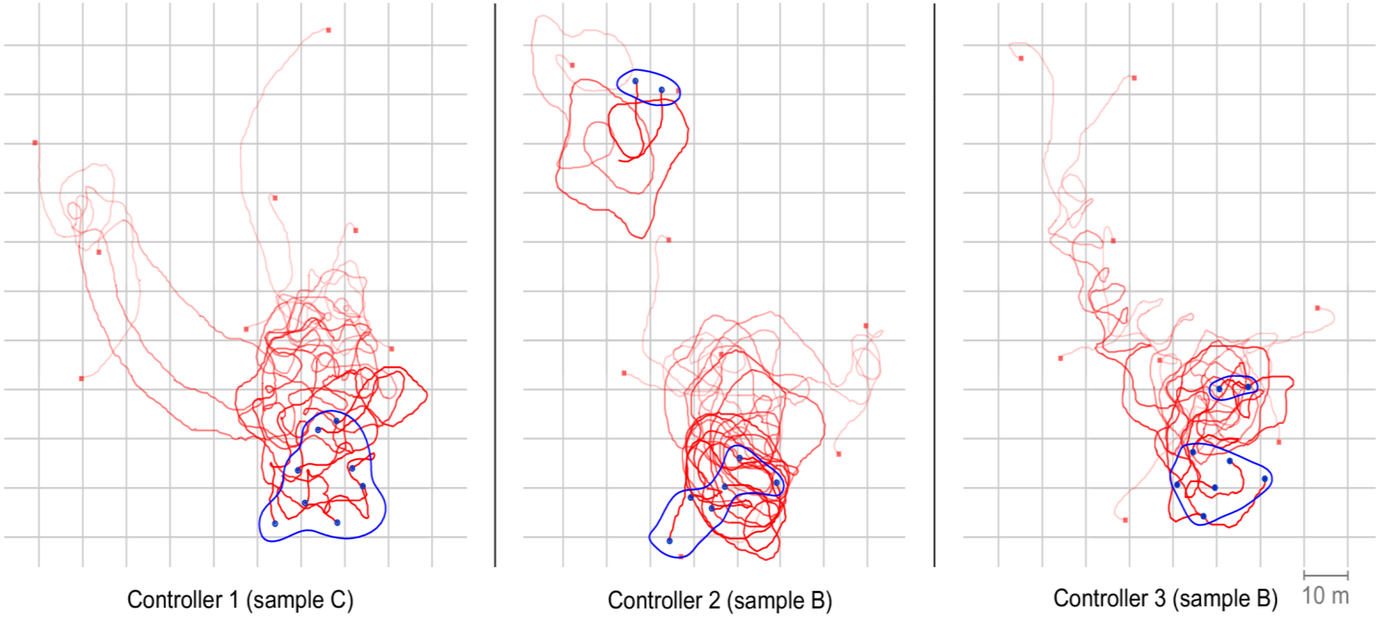
# Results cont.

- Clustering

Robots placed in an area of 100x100
40ms apart from each other
Time: 180 secs




https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0151834

# Discussion

- Properties of Swarm evident
  - Robustness: Observed during monitoring tasks
  - Flexibility: Observed during different coordination tasks
  - Scalability: Robots were removed
- Swarm behavior emerged during each task
- Swarm robotics for submarine mission under research.

# Conclusion

- Properties of Swarm robotics demonstrated
- Operating in real environment
- Result in simulation similar to real robots
- Verified key properties of swarm robotics

# Thanks for your attention

Questions

# References


1. Duarte, M., Gomes, J., Costa, V., Rodrigues, T., Silva, F., Lobo, V., … Christensen, A. L. (2016). Application of swarm robotics systems to marine environmental monitoring. *OCEANS 2016 - Shanghai*, 1–8. https://doi.org/10.1109/OCEANSAP.2016.7485429
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