PHASES AND PHASE TRANSITIONS IN THE COLLECTIVE DYNAMICS OF SIMPLE ROBOTIC FLOCKS

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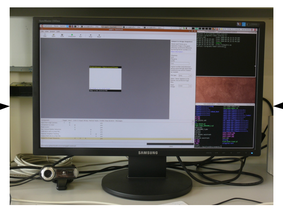
Abstract

We developed the first experimental setup of very simple self-propelled robots that show collective behavior based on only inelastic collisions in a two dimensional toroidal space. A circular swimming pool and cheap commercial RC boats were used to observe different flocking related phenomena that had been suggested by many theoretical models before. We proved that noise level has a fundamental role in the generation of collective dynamics and showed that jamming, flocking and disordered motion are all parts of the world of such a simple experimental setup. Critical noise ranges were examined and characteristics of both first and second order phase transitions were found. Our work was extended with a simulation model, too, and high similarity between real and simulation results were observed.

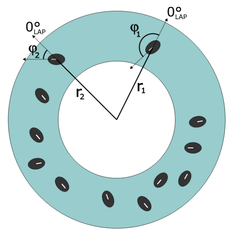
Simple Experimental Setup

PC + SwisTrack*

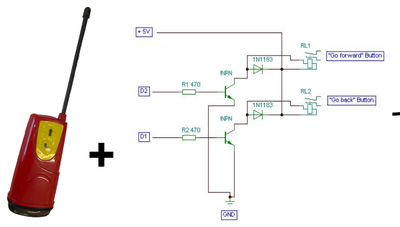


*http://sourceforge.net/projects/swistrack/

gigE camera



Local Angle Polar Coordinates



computer driven RC control

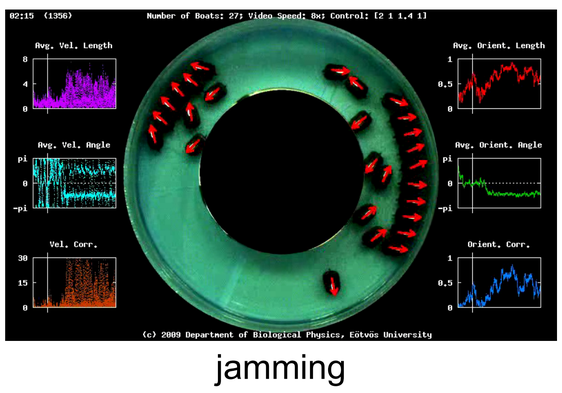
Circular pool with boats

Experiment Conditions

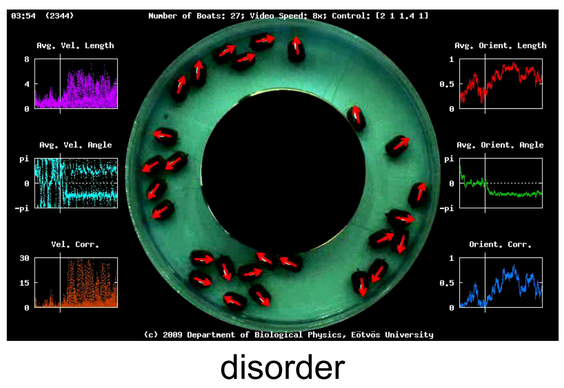
Parameter	Value	Unit
Outer diameter of toroidal pool	180	cm
Inner diameter of toroidal pool	97	cm
Size of boats	10x15	cm
Number of boats	27	pcs
RC control sequence [forward(fw) nop backward(bw) nop]	[2 1 x 1], where xϵ[0.6, 2.4]	s
Speed of boats in *fw* phase	15 ± 5	cm/s
Angular velocity of boats in *bw* phase*	±1 ± 0.2	1/s
Image resolution	800x800	pixel
Recording framerate	10	FPS
Determined and saved parameters for each boat in each frame	position, orientation, time (+ common control signal, video frame)	cm, rad, ms
Length of measurements	10-15	min

*Since boats turn in *bw* phase, ***bw* phase length** was taken as the **noise level** added to the system.

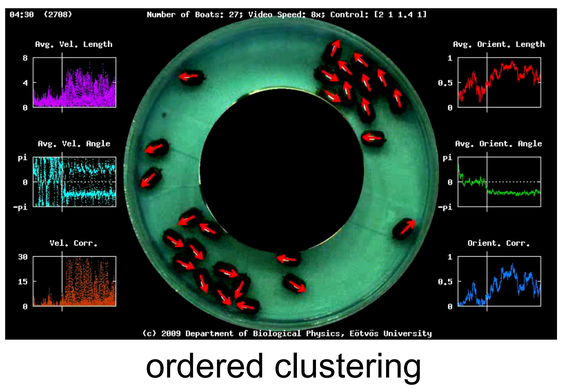
Visually Identified Dynamic Phases



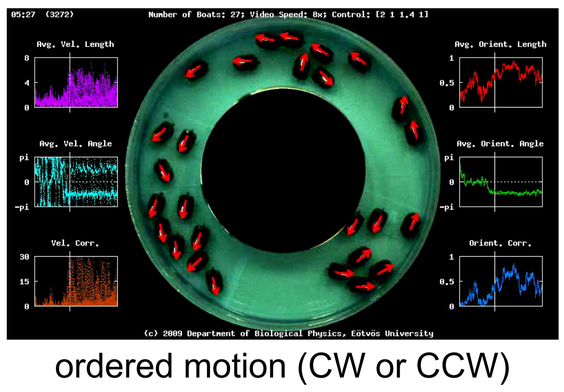
jamming



disorder



ordered clustering

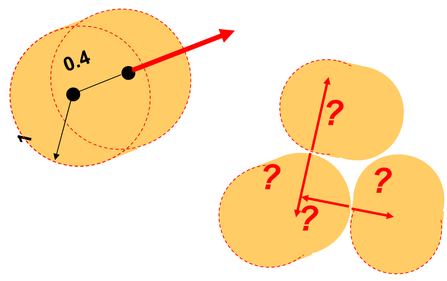


ordered motion (CW or CCW)

Numerical simulation of boat dynamics

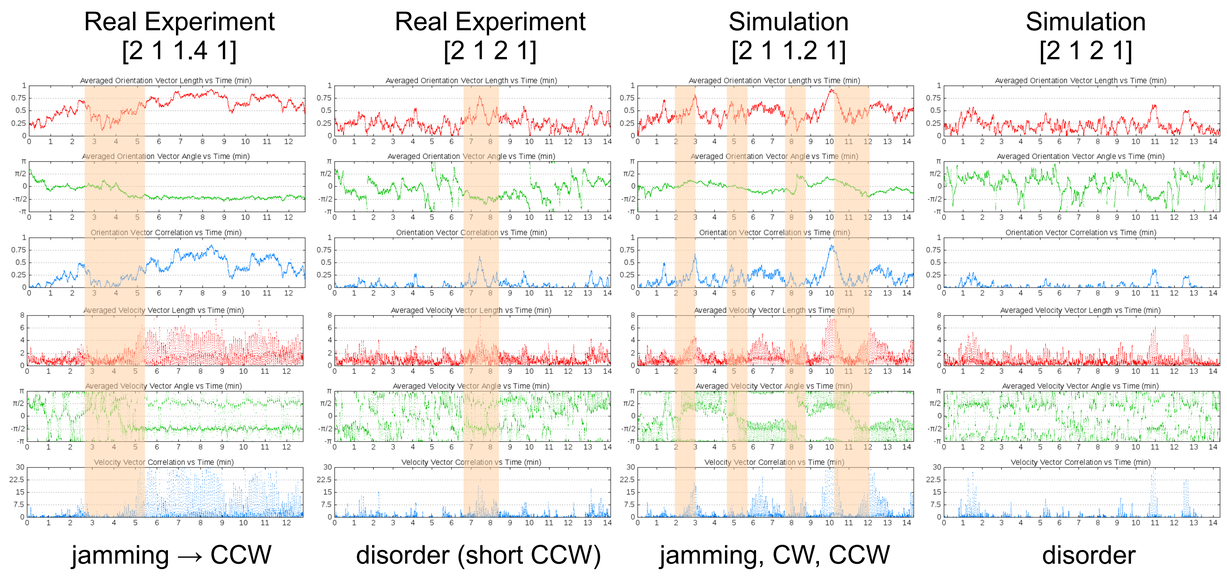
Ships are subject to:
- propulsion (forward/backward)
- propulsive torque if moving backwards
- damping by linear drag force, and torque

Collisions are assumed to be
- perfectly inelastic
- frictionless



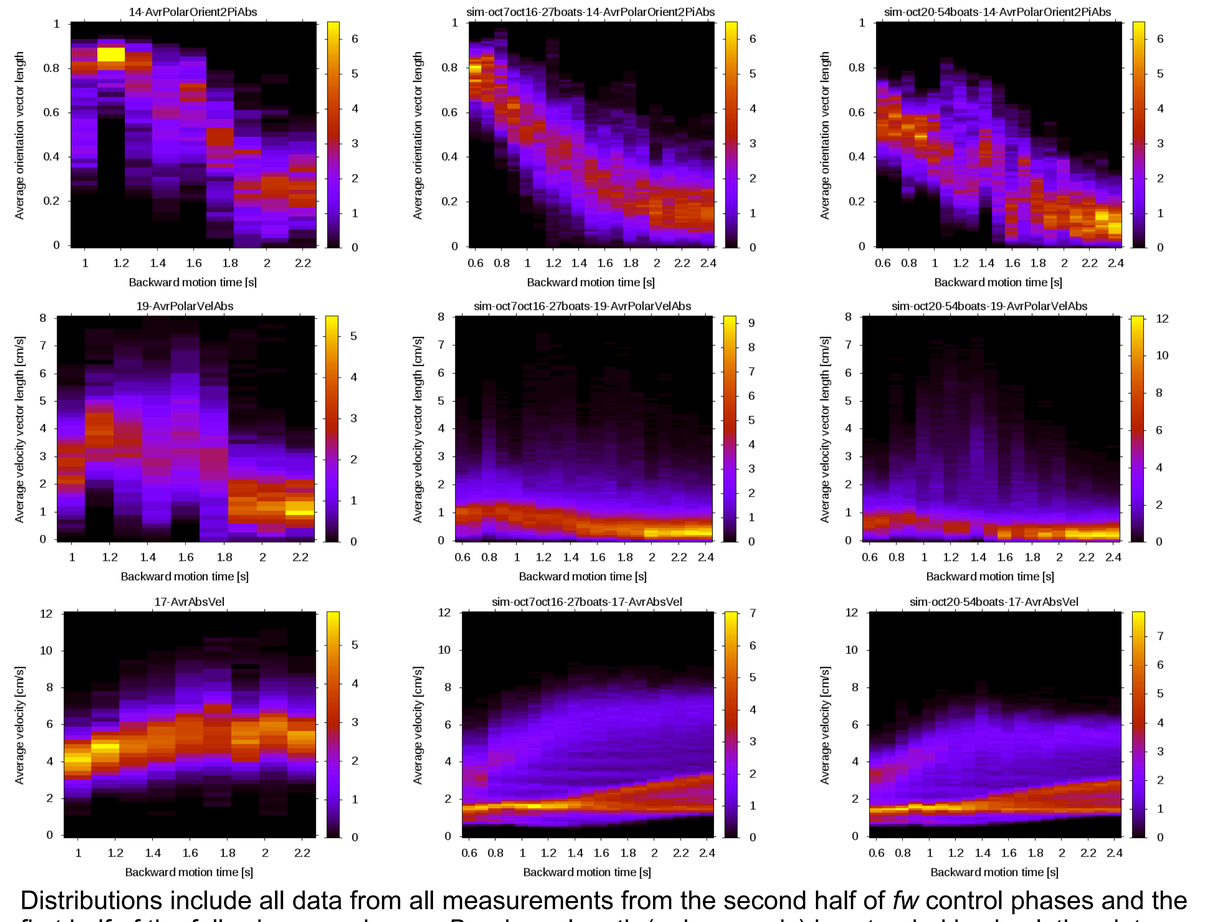
The full dynamics is simulated using the Principle of Least Constraint
- a variational principle
- does not require determination of unknown contact forces
- handles sudden collisions and continuous contact in a common framework

Order Parameters vs Time



jamming → CCW | disorder (short CCW) | jamming, CW, CCW | disorder

Order Parameter Density Functions vs Noise



Distributions include all data from all measurements from the second half of *fw* control phases and the first half of the following *nop* phases. *Bw* phase length (noise, x-axis) is extended in simulation data.

Summary of New Findings

- Four different phases of collective motion were observed in an experimental SPP system with only inelastic collisions:
  a) jamming
  b) clustering
  c) ordered motion (in CW or CCW directions)
  d) disordered motion
- Phase transitions in time can be very sudden (first order)
- Noise level determines the overall state of the system
- Specific (nonzero) noise level is needed for ordered motion
- Phase transitions in the noise space are smooth (second order)
- Elongation of particles is needed in simulation for dynamic ordering
- Real and simulation results are similar but lack of friction affects simulation in jamming phase with nonrealistic dynamics

Acknowledgements

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