DIS Project: Group 5

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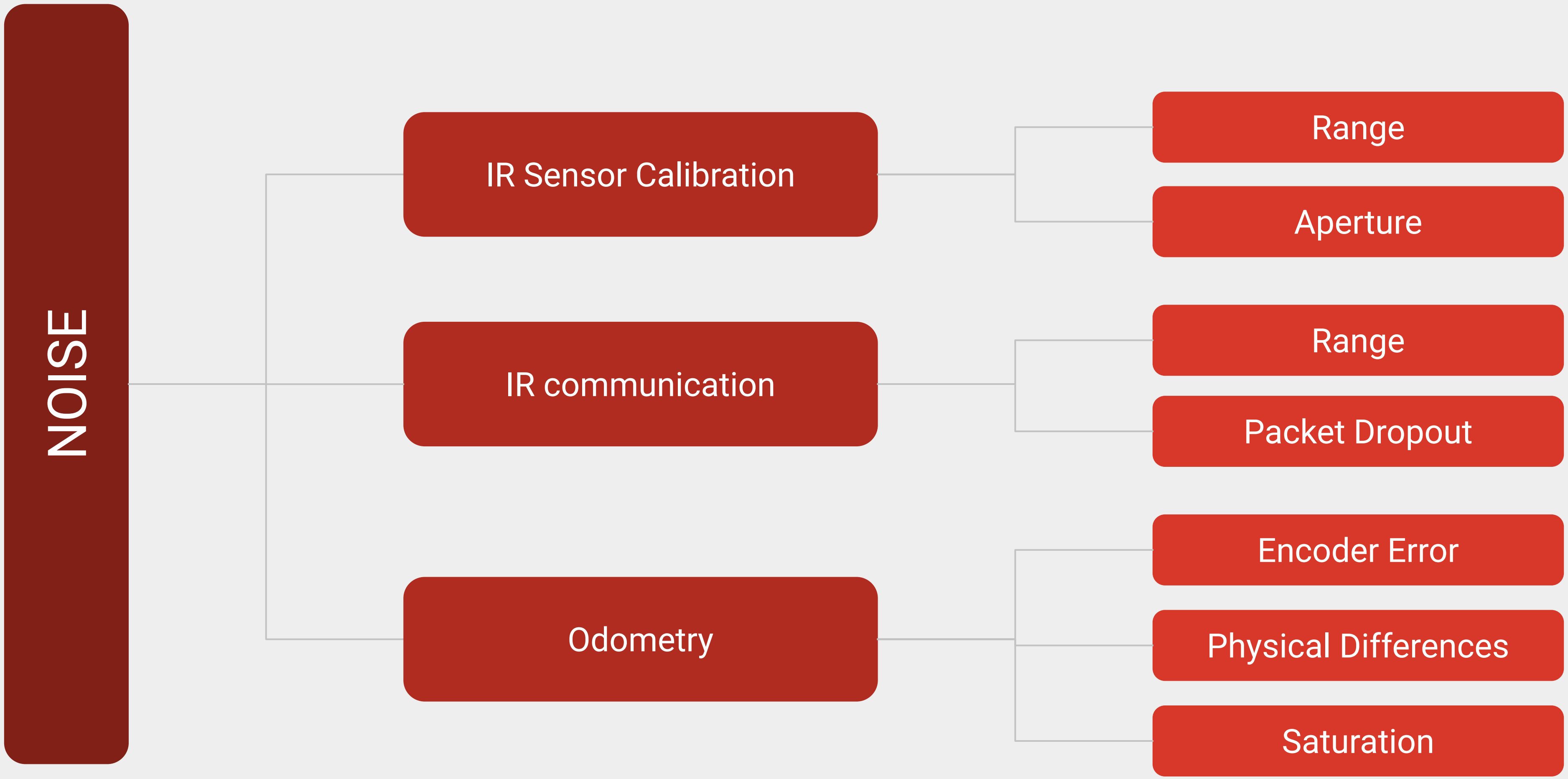
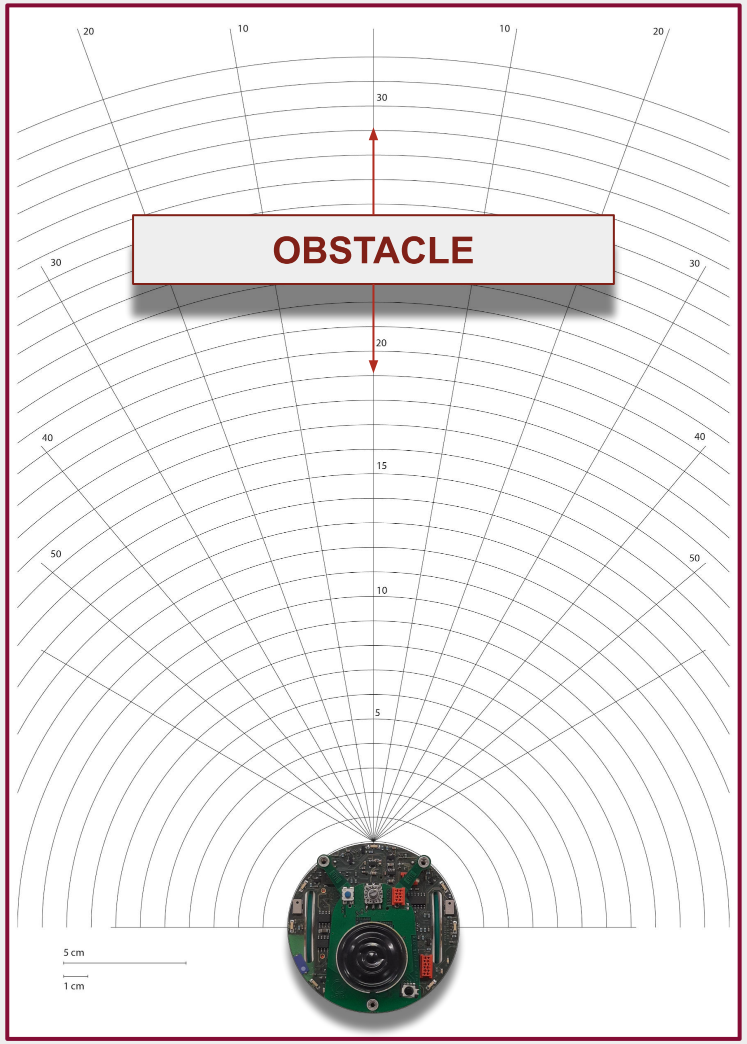
Methodology

1. Hardware Characterization
2. Noise modeling and implementation
3. Basic obstacle avoidance implementation
   - 3.1 PSO on obstacle avoidance
4. Basic flocking implementation
   - 4.1 PSO on flocking
5. Hardware implementation
6. Result analysis

Hardware characterization

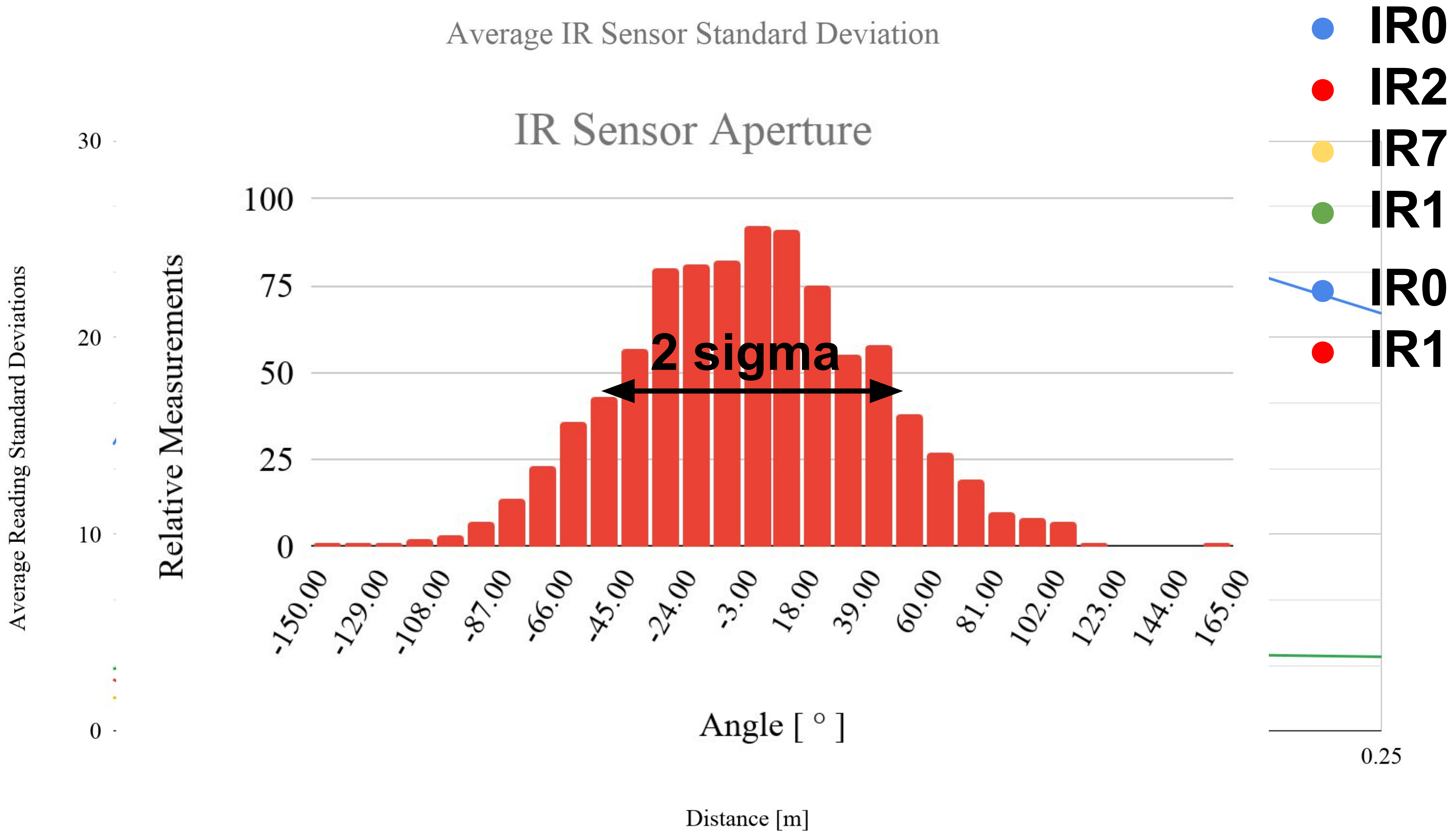


Hardware Characterization: IR Sensor

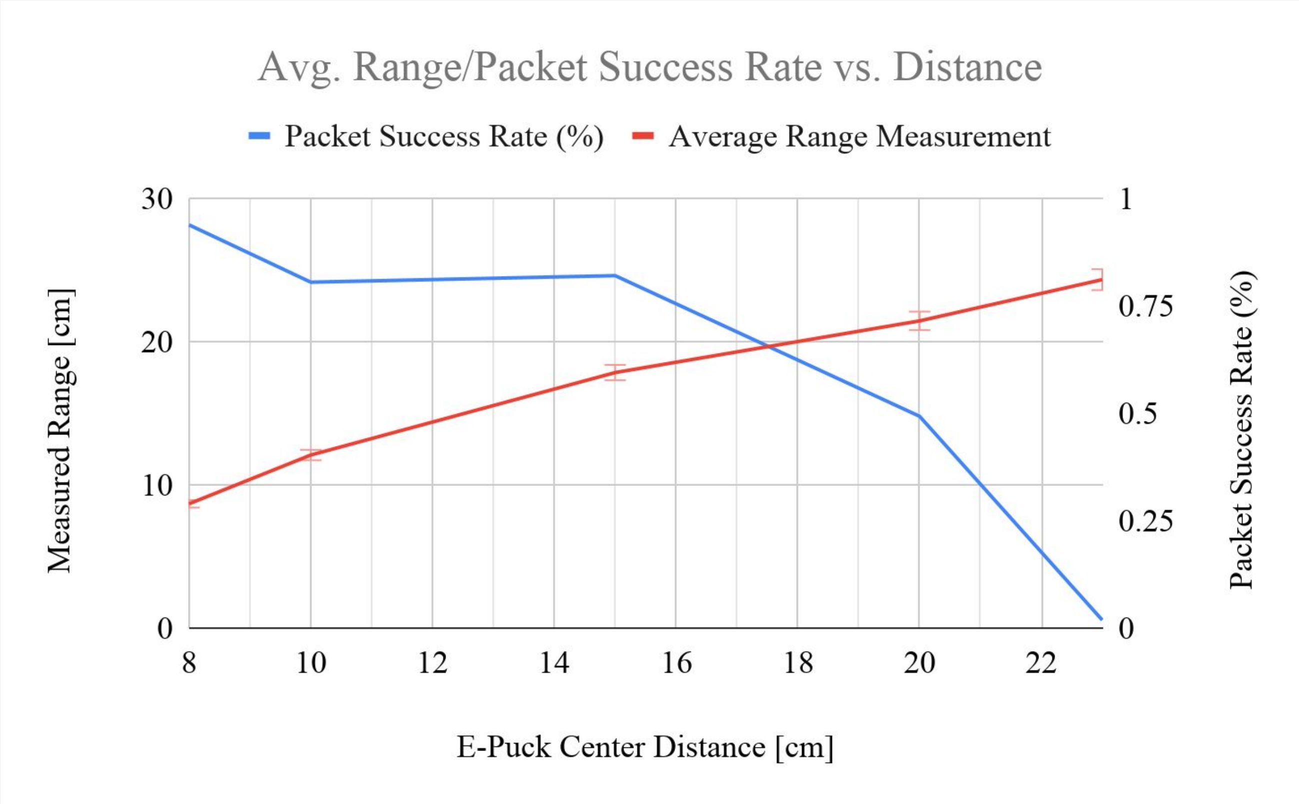


1. **2 baseline measurements** (no obstacle)
2. **9 distances** (white perpendicular obstacle)
3. **Sensor aperture** (by sweeping the obstacle)

Webots lookup tables


Average IR Sensor Standard Deviation
IR Sensor Aperture
IR0
IR2
IR7
IR1
IR0
IR1
Average Reading Standard Deviations
30
20
10
0
Relative Measurements
100
75
50
25
0
2 sigma
-150.00
-129.00
-108.00
-87.00
-66.00
-45.00
-24.00
-3.00
18.00
39.00
60.00
81.00
102.00
123.00
144.00
165.00
Angle [°]
0.25
Distance [m]

Hardware Characterization: IR Communications



- ➪ **Reliable range** estimation
  (σ ≃ 0.61cm @ 20 cm)
- ➪ **80% packet success** rate up to 15 cm

Hardware Characterization: Odometry

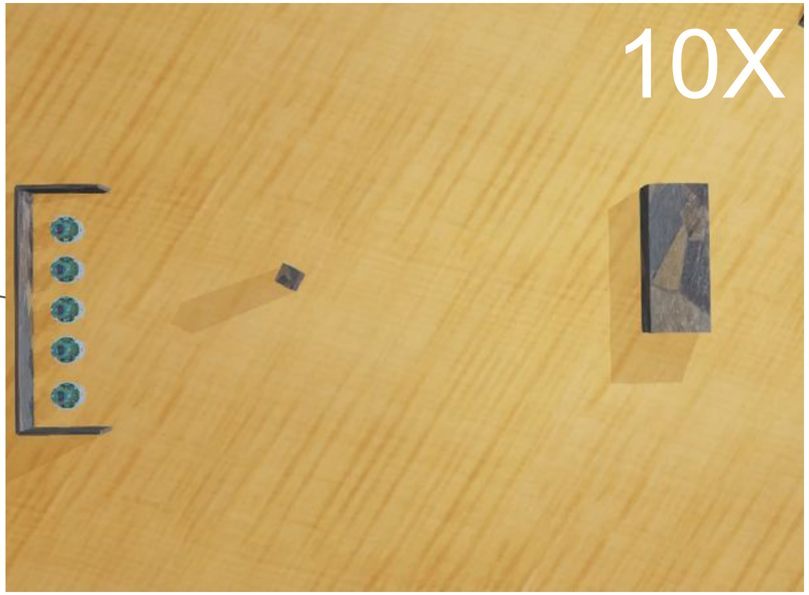
e-Puck	Axle Length [ground]	Wheel Diameter
99	5.293 cm	4.102 cm
77	5.345 cm	4.101 cm
56	5.279 cm	4.103 cm
STD	***0.086 cm***	***0 cm***

- Physical dimensions of each robot measured
- Validation through **rotation and forward-motion tests**:
    - Forward tests over 600 mm
        - ↳ **4 mm** error (**0.8%**)
    - Rotations test over 20 consecutive 180° rotations
        - ↳ **71.3°** Avg. Error (**1.98%**)

⇨ Modeled as **Gaussian noise** on both motor speed and axle length

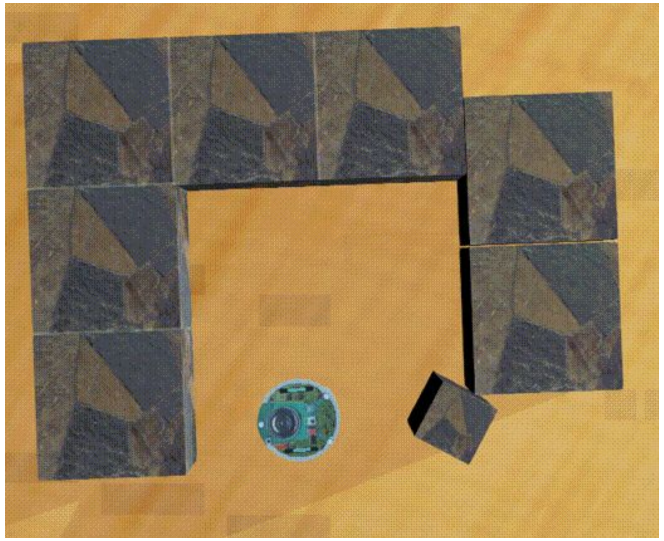
Simulated Hardware

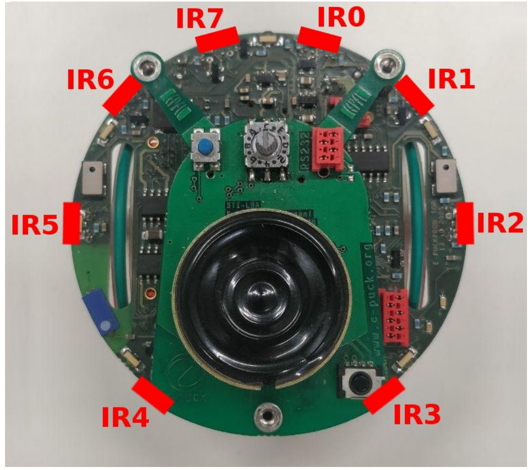
Dropping communication quality



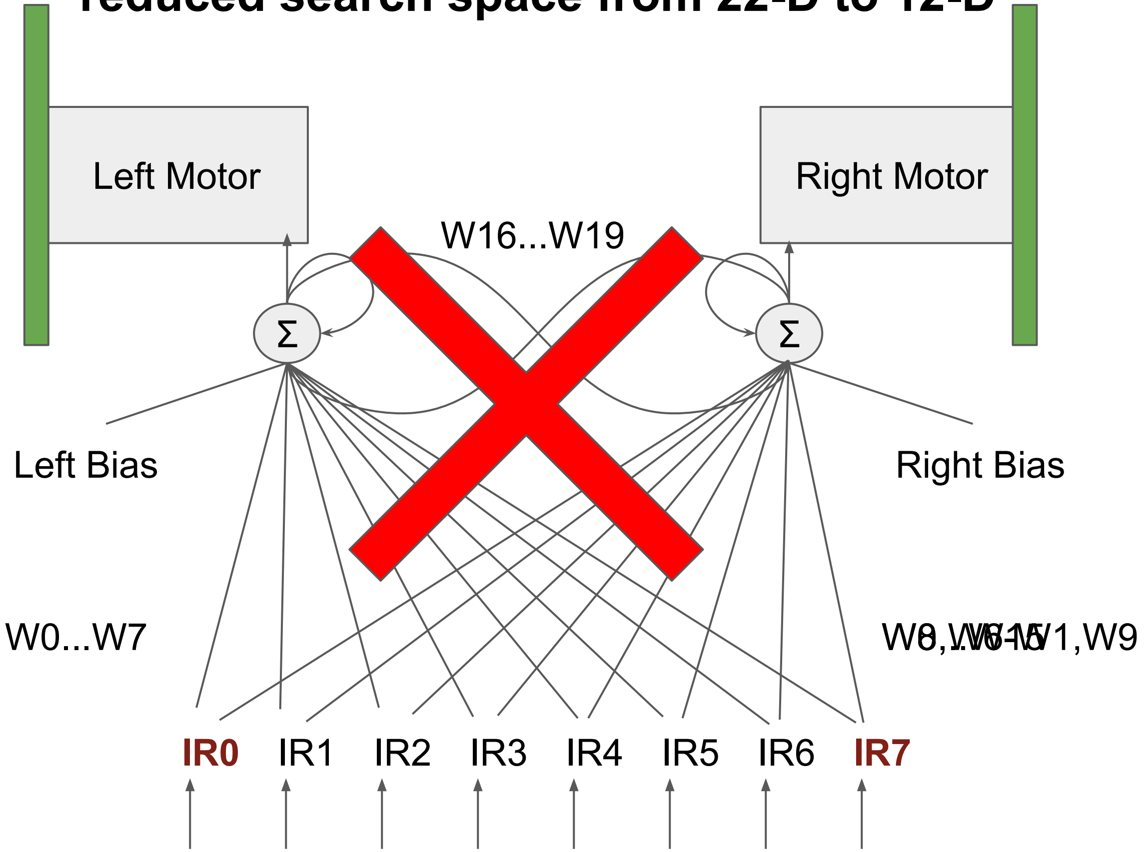
Odometry noise

Obstacle avoidance implementation:





Assuming (partial) symmetry
reduced search space from 22-D to 12-D

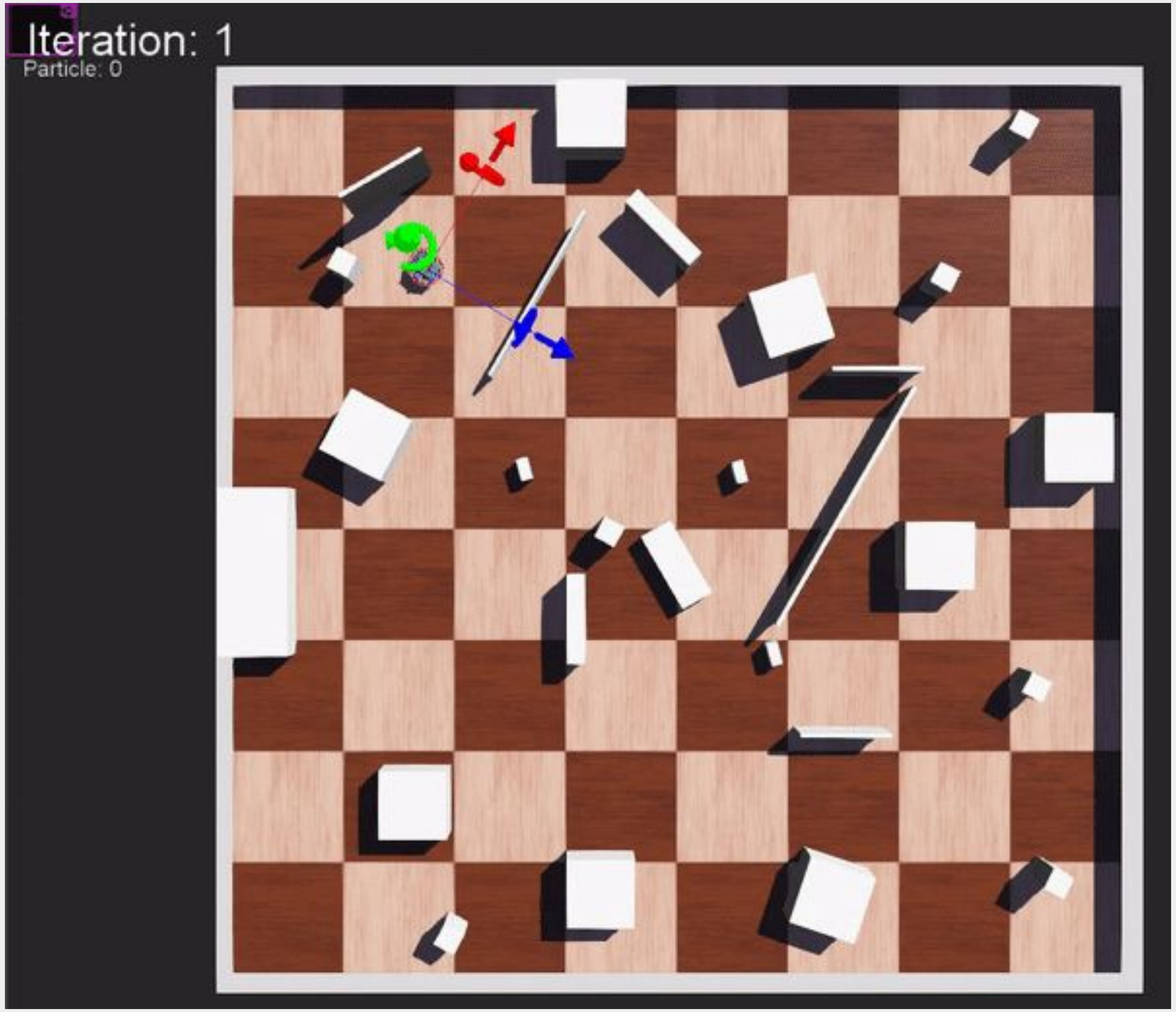


Single Robot P-Best PSO[2] on obstacle avoidance

- Fitness $= |V|(1-\sqrt{\Delta V})(1-IR_{max})$ [1]

- Hyper-parameters:
  - Nparticles = Data Size (22, 12)
  - Standard Neighborhood
    - # Neighbors = 2
  - 5 Runs x 100 Iterations x 30s (simulated time)

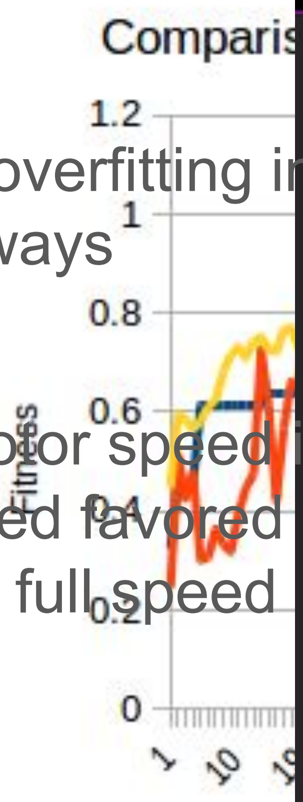
- Random initial robot location on diverse, cluttered map

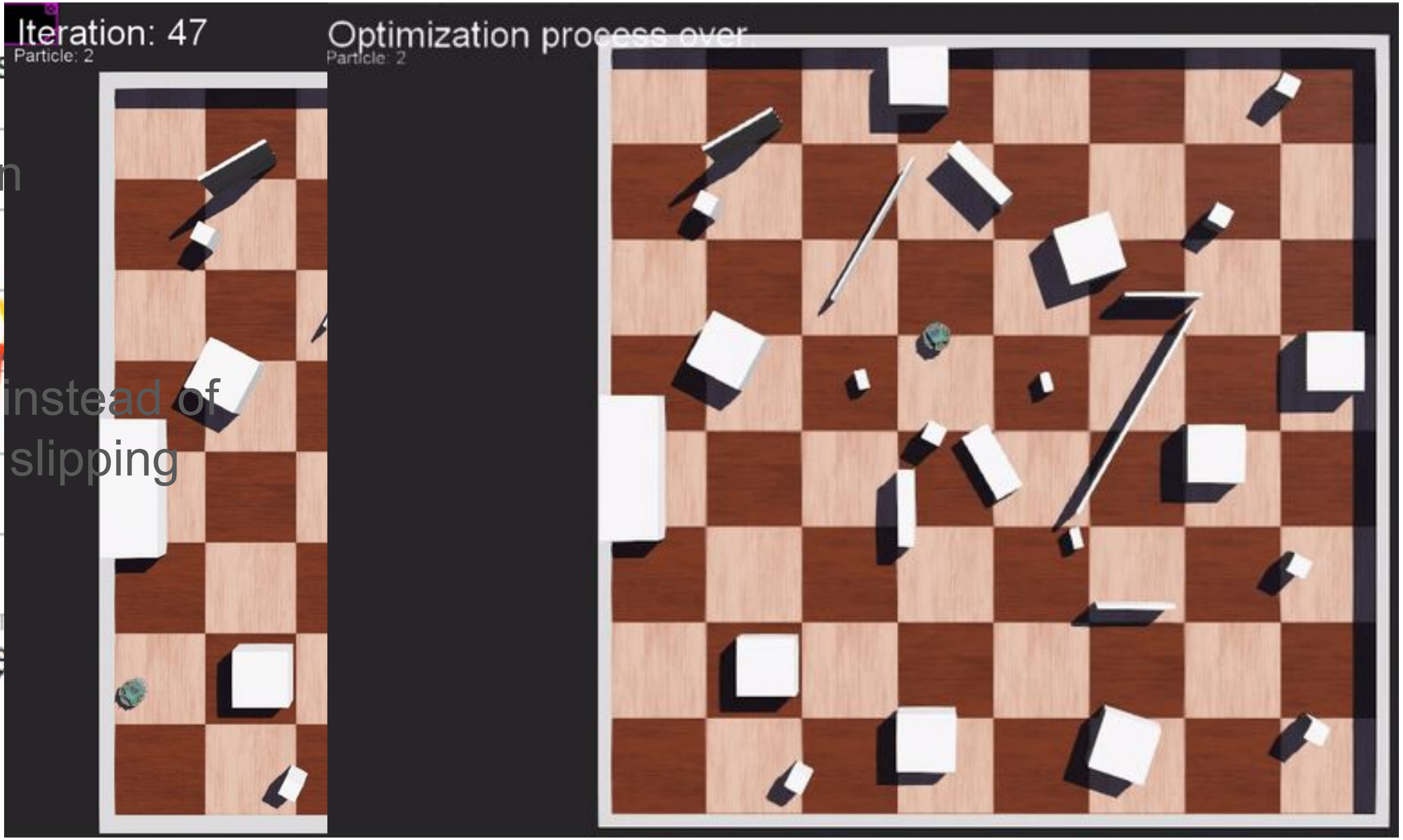


[1] D. Floreano and F. Mondada, Evolution of homing navigation in a real mobile robot, 1996
[2] E. Di Mario, I. Navarro, and A. Martinoli, A Distributed Noise-Resistant Particle Swarm Optimization Algorithm for High-Dimensional Multi-Robot Learning

Single Robot PSO on obstacle avoidance

- Possible overfitting in straightaways
- Use of motor speed instead of robot speed favored slipping wheels at full speed

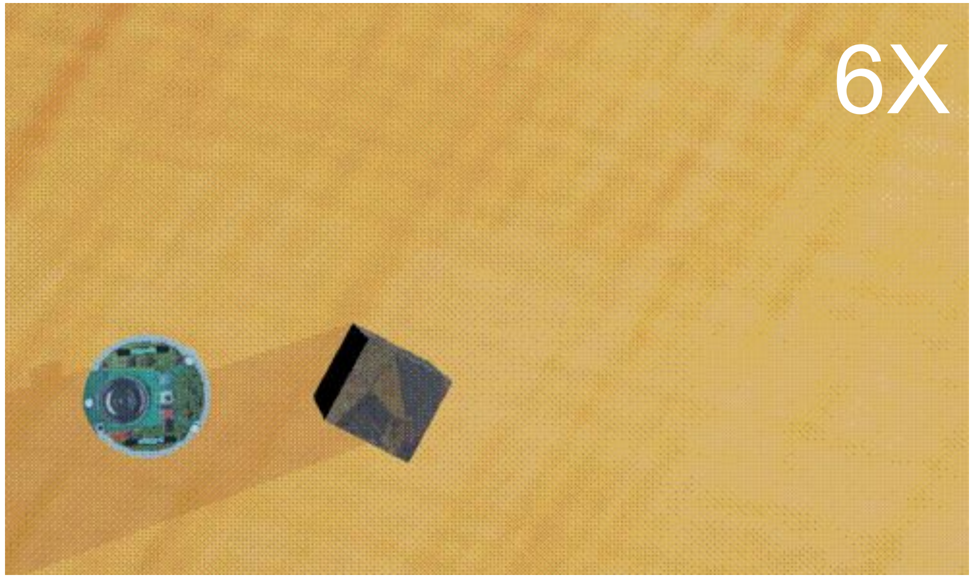


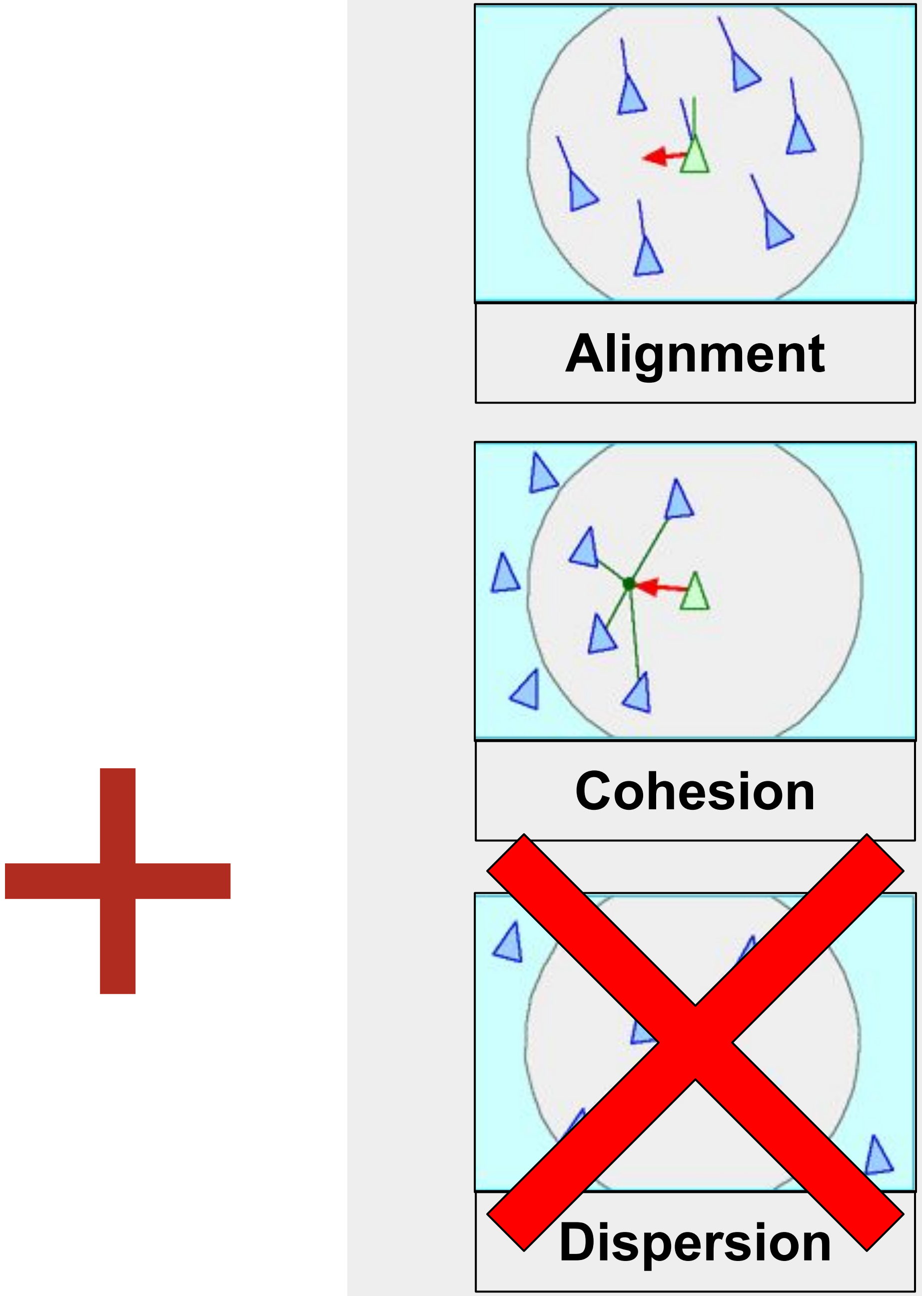


Flocking implementation

Reynolds' flocking[3]

- **Dispersion rule** substituted by **Braitenberg**
- Heading **P controller**



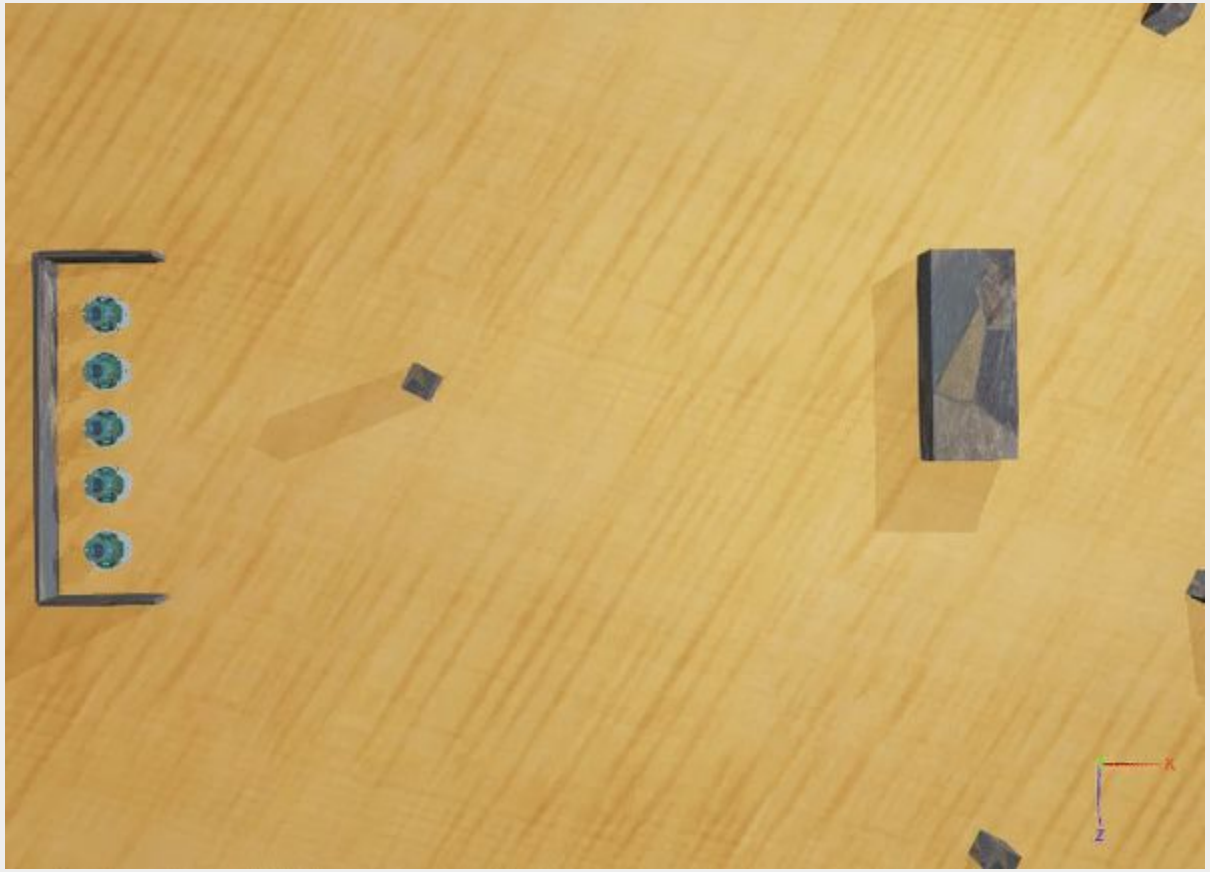


[3] Reynolds, "Flocks, herds and schools: A distributed behavioral model.", 1987

Flocking implementation
Flockmate re-acquirement

- Controller keeps **leaky-memory** of the flock position

1. Flock loses one e-Puck:
   - ↳ Flock keeps memory of its last position:
     - ↳ Flock slows down
2. One e-Puck loses the flock:
   - ↳ e-Puck keeps memory of the last position of the flock:
     - ↳ e-Puck tries to rejoin the flock



Flock Behaviour P-Best PSO

Public, group, homogeneous

Hyper-parameters:

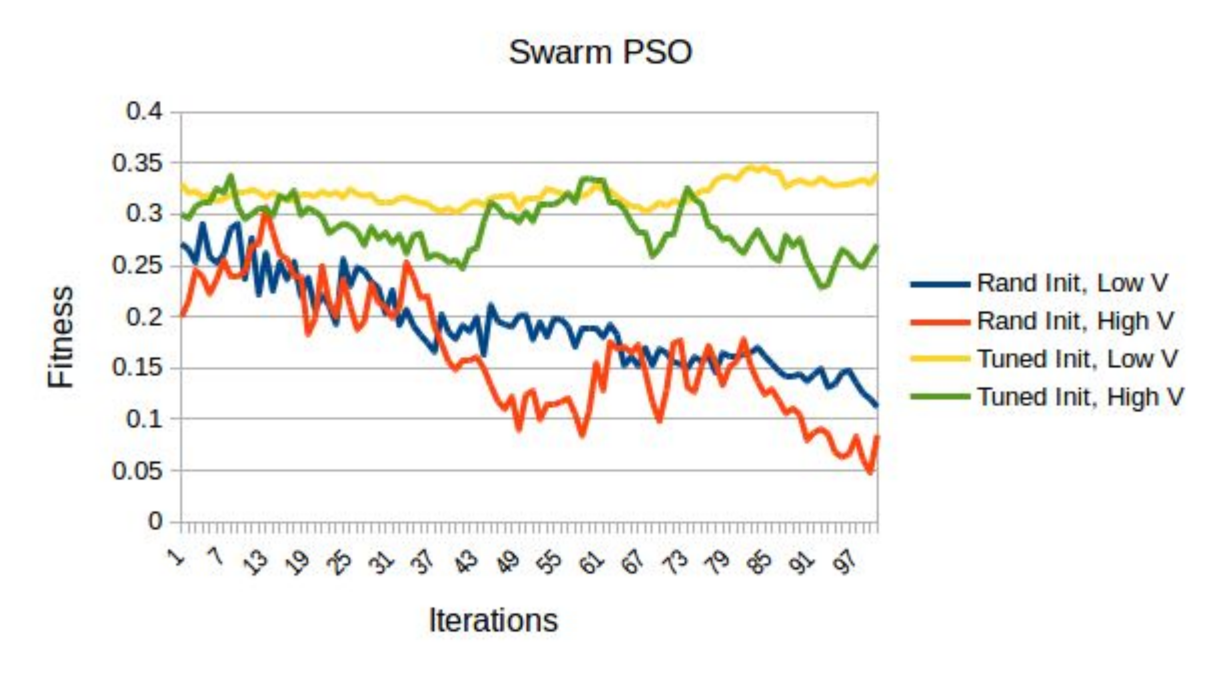
- Nparticles = 2 **x** Data Size (2 **x** 7)
- Standard Neighborhood
  - # Neighbors = 3
- 5 Runs **x** 100 Iterations **x** 30s (simulated time)

Random particle position, velocity

Random obstacle positions

$$o[t] = \frac{1}{N}\left|\sum_{k=1}^{N} e^{i\psi_k[t]}\right|$$

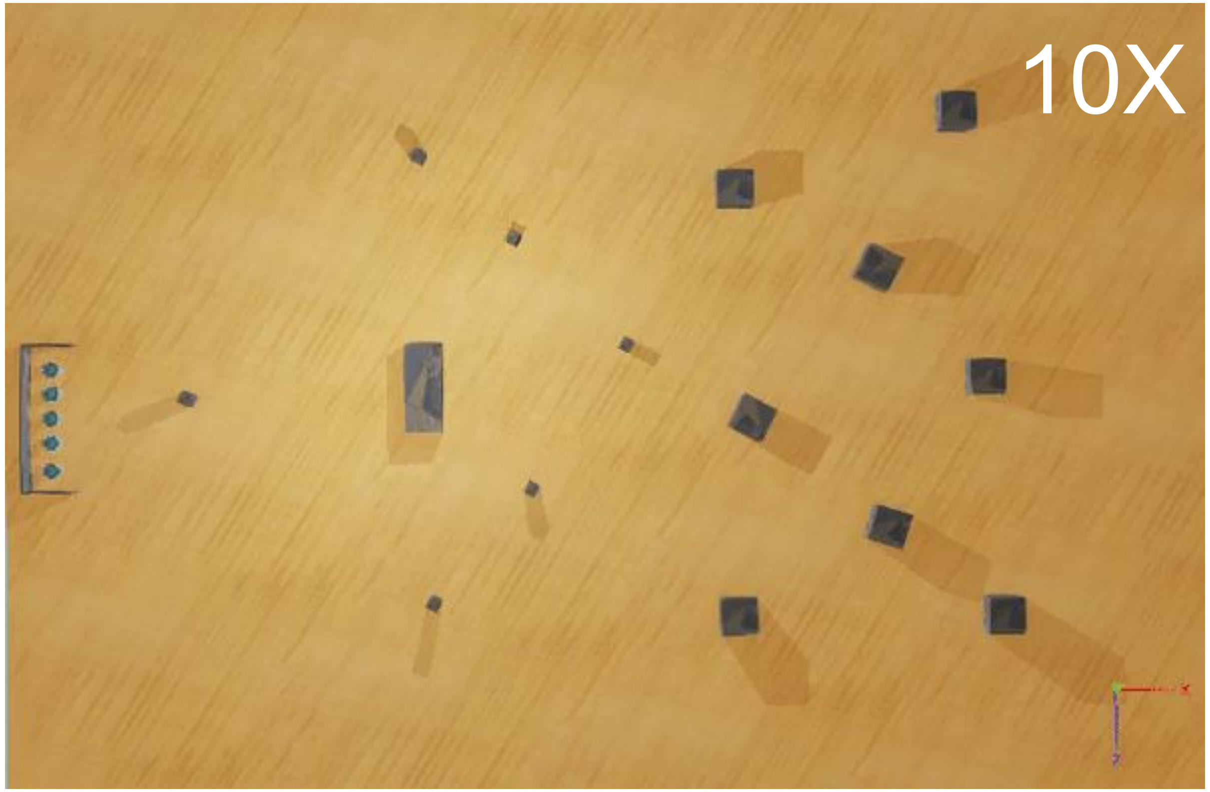
$$c[t] = \left(1 + \frac{1}{N}\sum_{k=1}^{N} dist(x_k[t], \hat{x}[t])\right)^{-1}$$



Results in simulation

With perfect communication below 25cm

10 runs
Mean: 0.278
Std: 0.021



Obstacles
(arena 1)

10 runs
Mean: 0.253
Std: 0.024

Crossing
(arena 2)

Impact of Simulated Noise

10 runs
Mean: 0.192
Std: 0.021

Odometry error (4%)
Package drop above 25cm

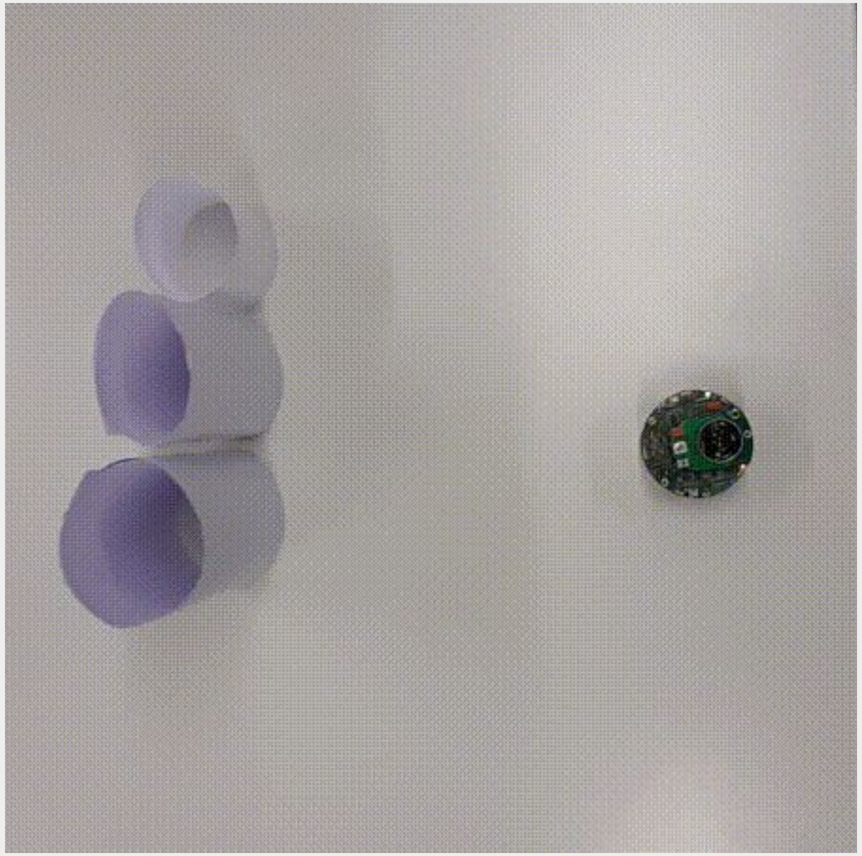
10 runs
Mean: 0.289
Std: 0.018

Perfect odometry
Perfect communication

Porting to hardware

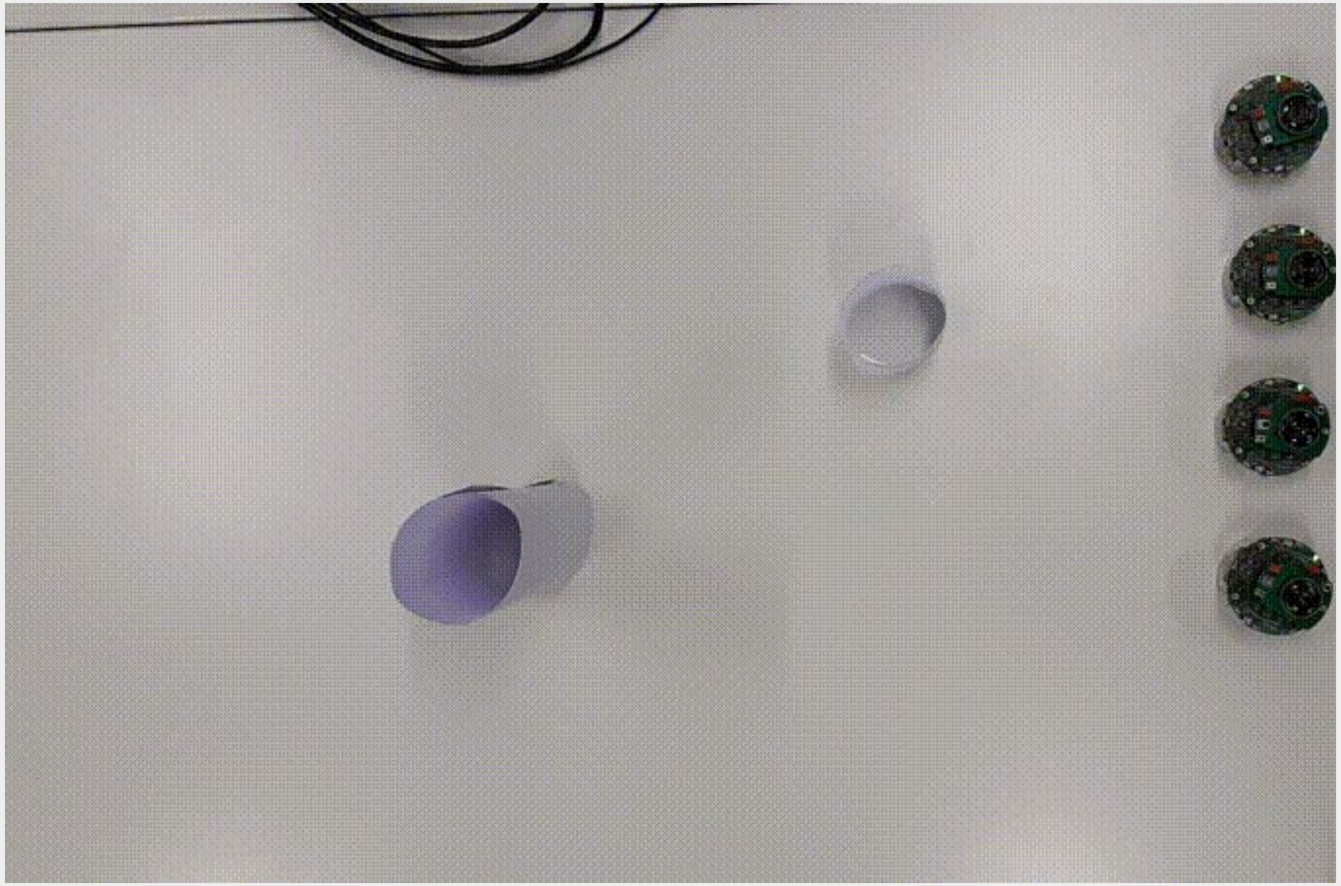
- **Braitenberg**

- **P-controller on the heading**



Porting to hardware

- **“Flocking”**

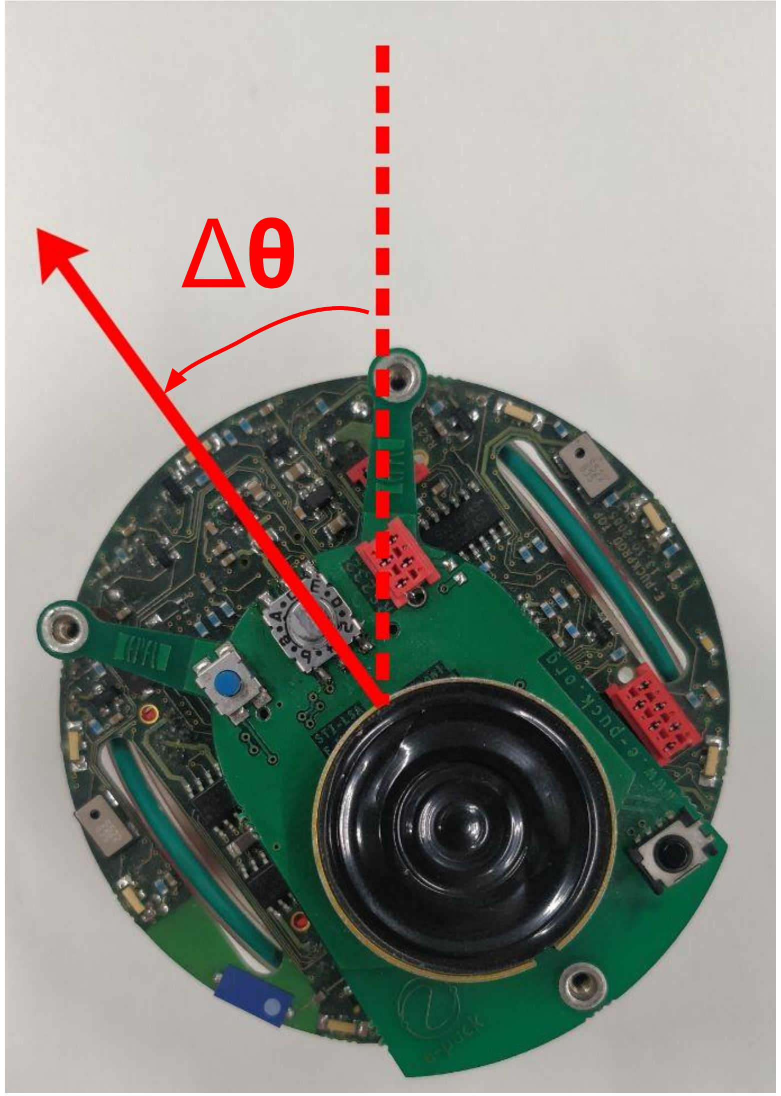


1 Million and 1 things to improve

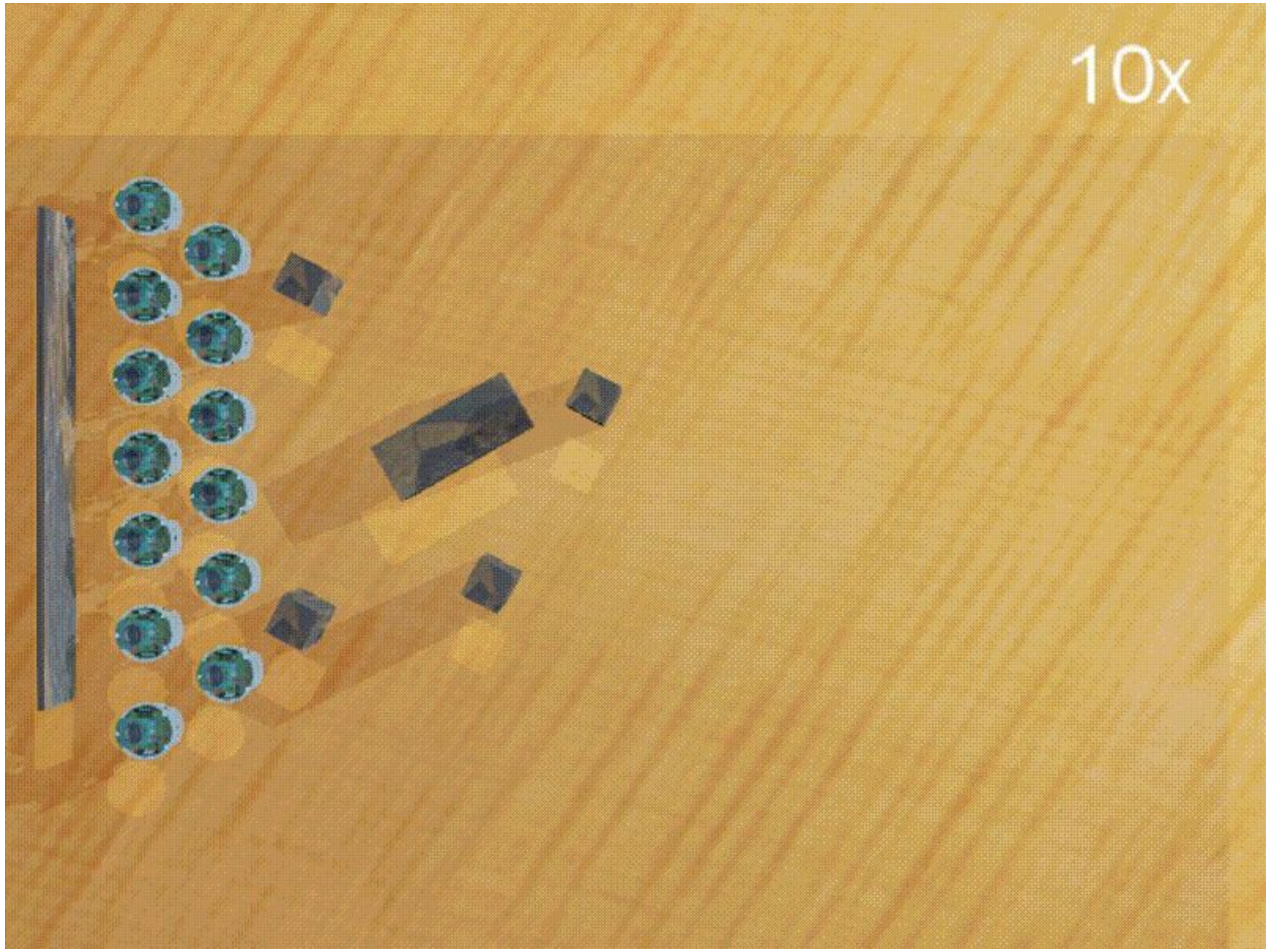
- Start with the basics
  - Spend less time on hardware characterization
  - Spend more time on porting to hardware
- Investigate PSO issues
  - Poor hyper-parameter tuning or implementation issue?
  - Consider training obstacle avoidance using multi-robot heterogeneous PSO
- Consider more advanced control policies for group behaviour
  - Path following instead of heading control
  - Shared state information using unused R&B bandwidth (Kalman filter)
  - Inter-team communication for improved avoidance

Thank you for your attention

Appendix A: Heading error

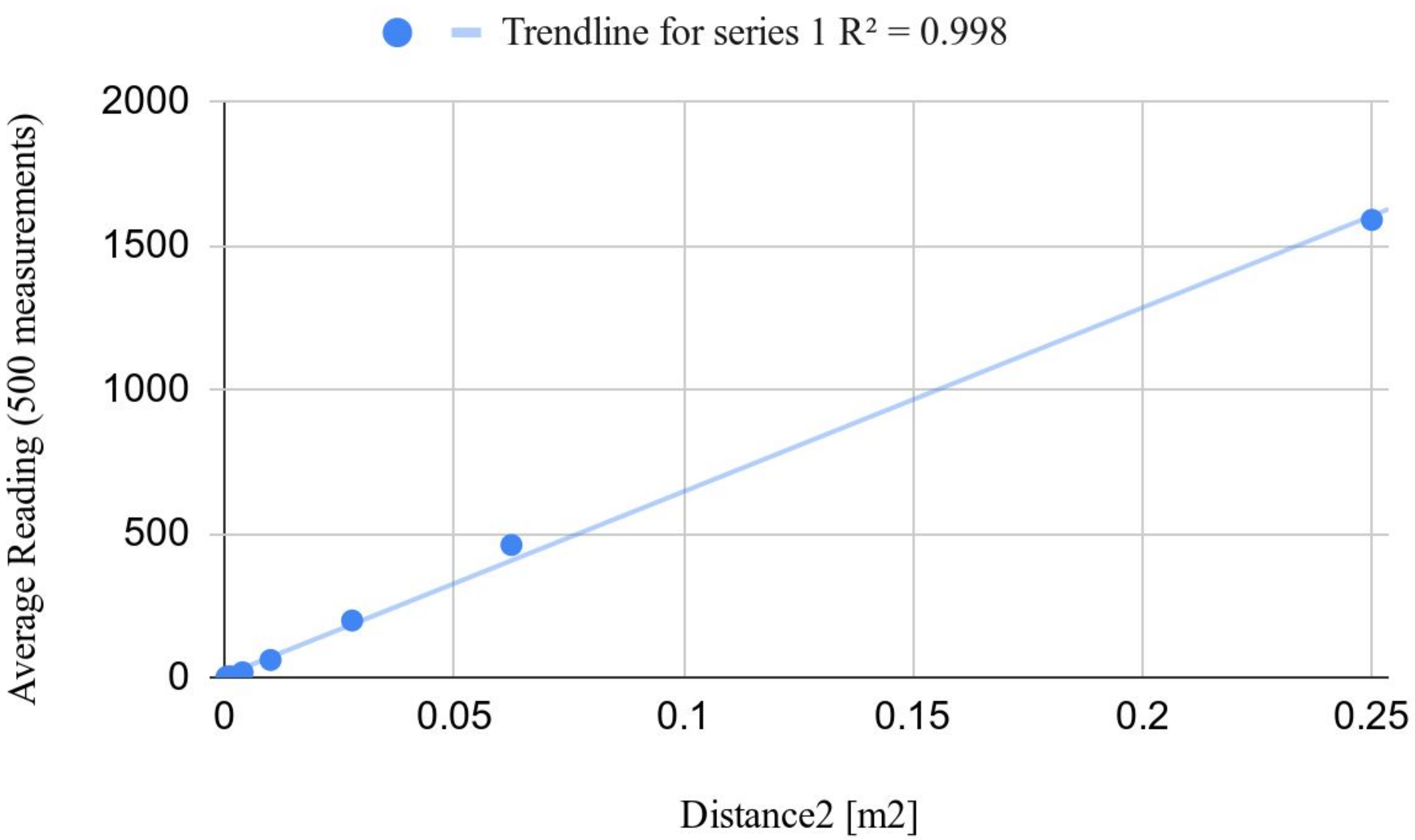


Appendix B:
13 epucks: No noise, 25cm communication

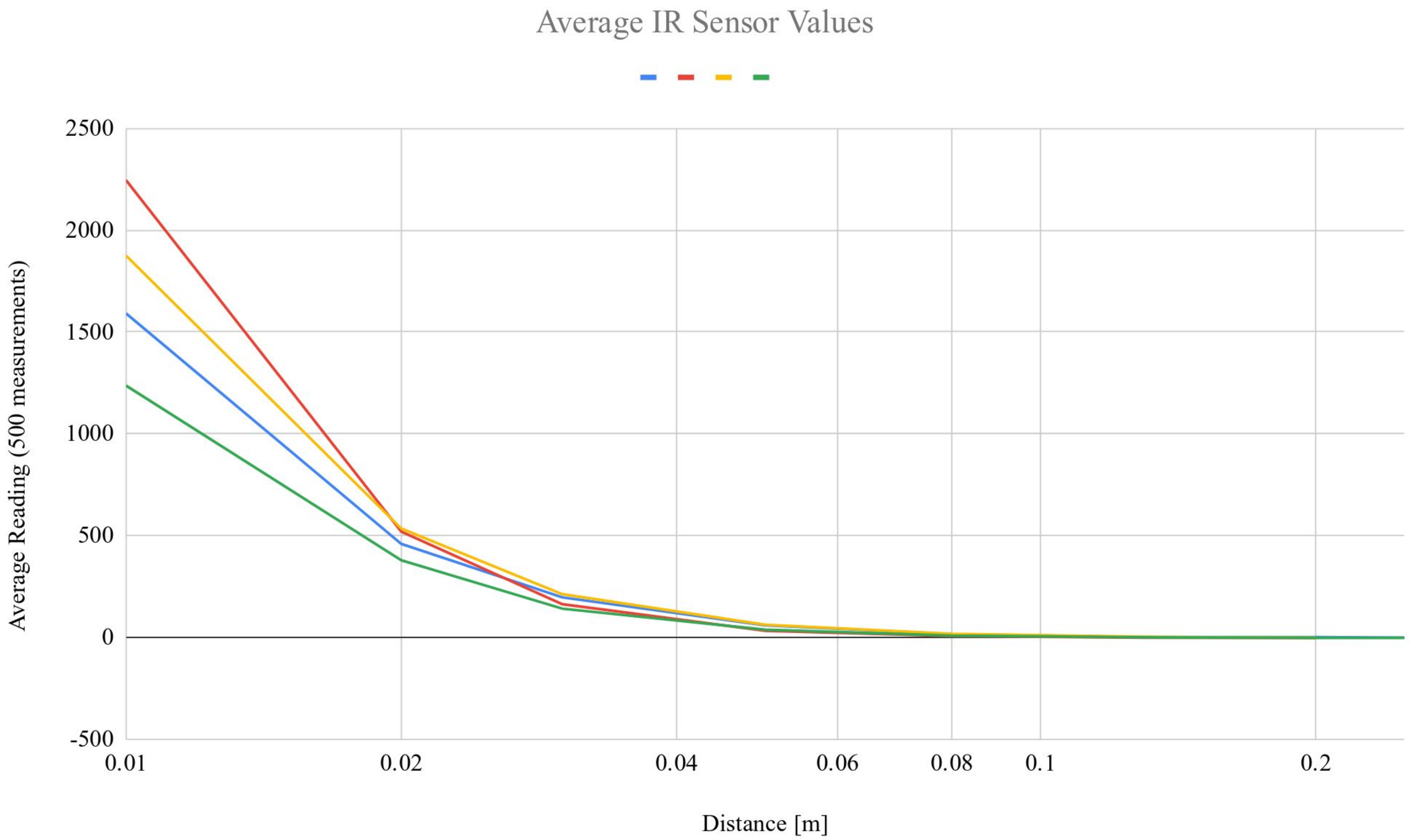


Appendix C:
Crossing with package dropout and odometry noise

Appendix D:

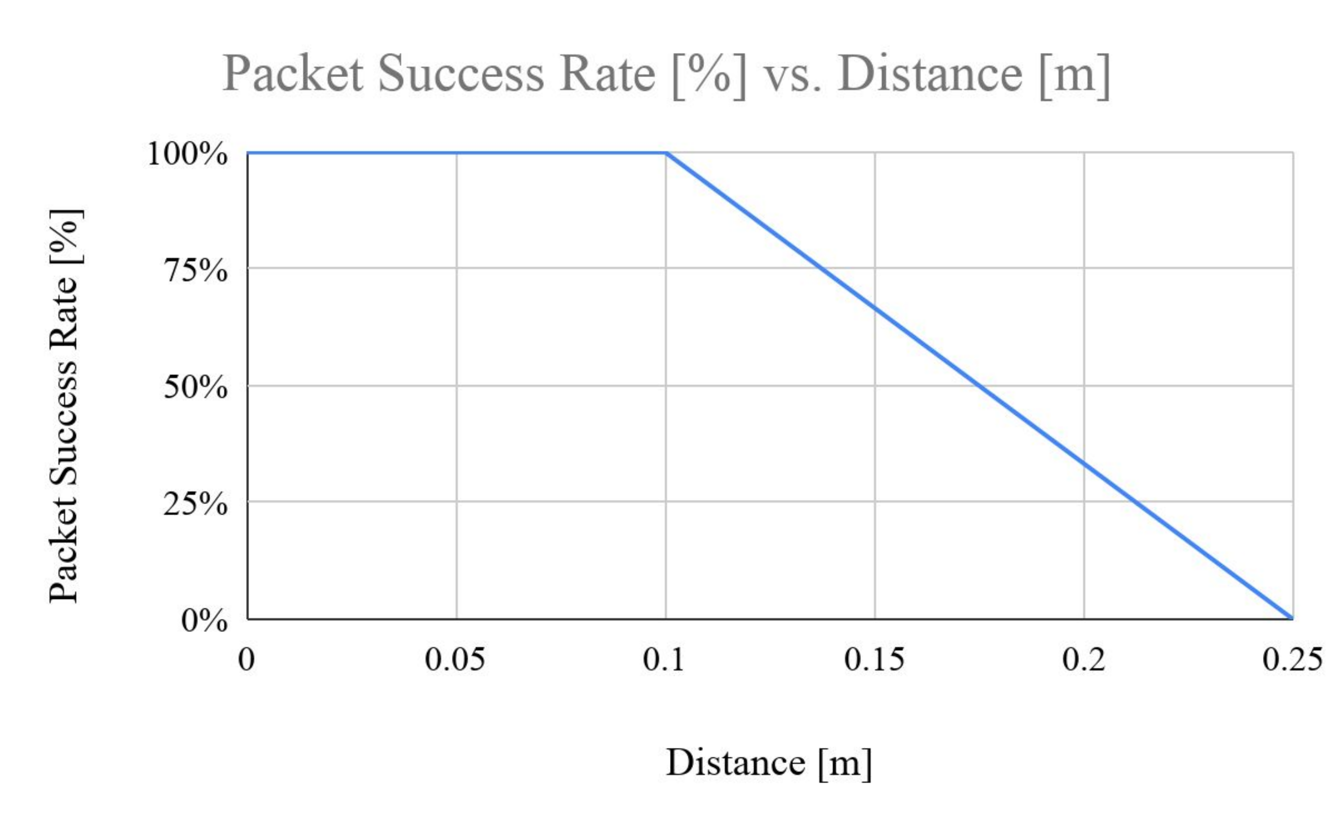

Trendline for series 1 R² = 0.998
2000
1500
1000
500
0
0
0.05
0.1
0.15
0.2
0.25
Average Reading (500 measurements)
Distance2 [m2]

Appendix E:



Average IR Sensor Values
2500
2000
1500
1000
500
0
-500
Average Reading (500 measurements)
0.01
0.02
0.04
0.06
0.08
0.1
0.2
Distance [m]

Appendix F: Packet drop-out implementation



- **100% success** up to 10 cm
- **Linear degradation** with distance

Appendix G:

ROTATION TEST		
e-Puck No.	**Total Error**	**Error / Rotations**
99	10.15 deg	1.02 deg
77	72.32 deg	7.23 deg
56	114.66 deg	11.46 deg
FORWARD MOTION TEST		
e-Puck No.	**Total Error**	**Error / Distance**
99	4.5 mm	0.75%
77	3.6 mm	0.60%
56	4.1 mm	0.68%