Biologically inspired mobile robot control robust to hardware failures and sensor noise

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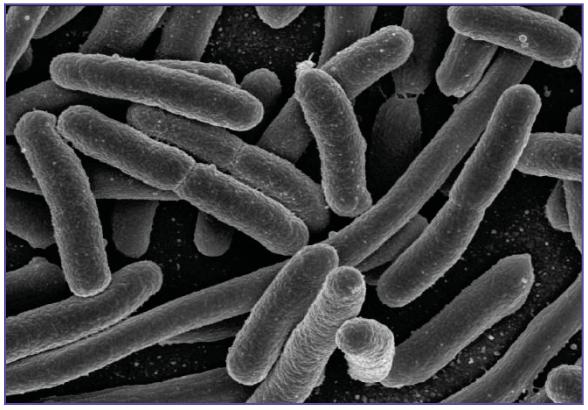
Background

- Robots need to cope with world uncertainties
  - Noise
  - Hardware failures

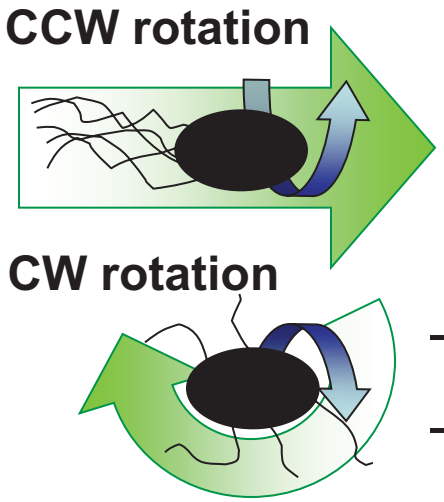
- Many advances techniques were proposed

E.g. Bongard, J., Zykov, V., Lipson, H.: Resilient machines through continuous **selfmodeling**. Science 314(5802), 2006



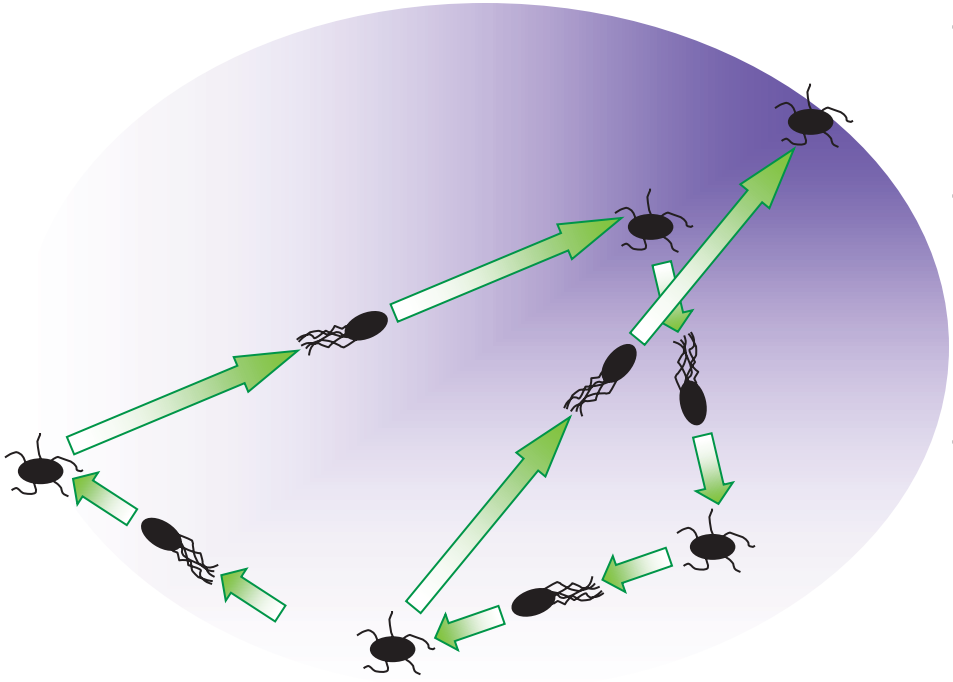
- Bacteria cope with strongly noisy information despite their simplicity
  - E.g. Escherichia coli chemotaxis

Escherichia Coli chemotaxis



E. Coli presents two movements

- Flagella are aligned in a single bundle
- **proceed in a straight line**
- Flagella bundle is broke apart,
- **tumble in place, random direction change**



- Proceeds by alternating the two movements
- If positive attractants gradients (food increases)
  → longer straight swims
- Biased random walk toward attractants

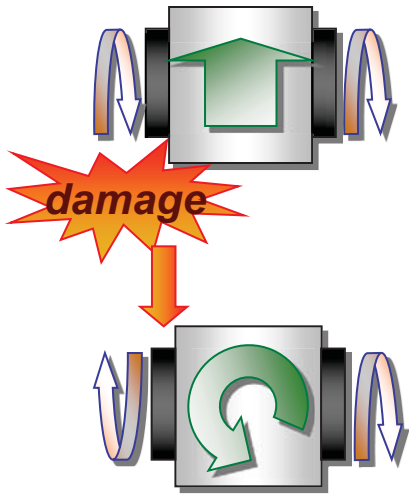
Adler, J.: The sensing of chemicals by bacteria. Scientific American 234 (1976), 40–4

E. Coli inspired robot navigation

- E. Coli biased random walk mimicked in robotics
  - A. Dhariwal, G. Sukhatme and A. Requicha, *Bacterium-inspired Robots for Environmental Monitoring*, *ICRA 2004*
- Pros
  - Performs well with noisy sensors/actuators
  - Multiple agents are better distributed in presence of multiple/ dissipative sources
  - Prevents ending up in local minima
- Cons
  - slow (for instance w.r.t. gradient descend)

Biased RW control

- Wheeled robot with two behaviors:
  - Straight movement
  - Random rotation
- Switching between the two behaviors
- Hardware faults can prevent reaching the target



Example: an encoder breaks
→a wheel rotates in the opposite direction
→ "go forward" becomes "spinning on itself"

Control space biased RW

Biased random walk in the ***motor command space*** → appropriate behaviors that exploit the working hardware are found

Bias term

Purposively added Random term

$$\dot{u} = \alpha A(x) f(u) + \beta \eta$$

Bias term coefficient

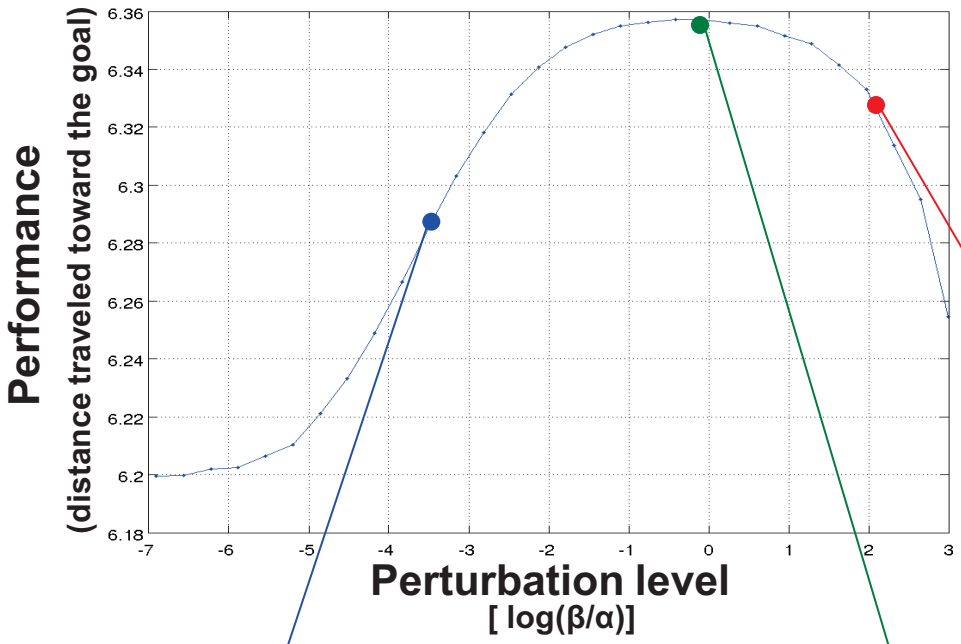
Random perturbation coefficient

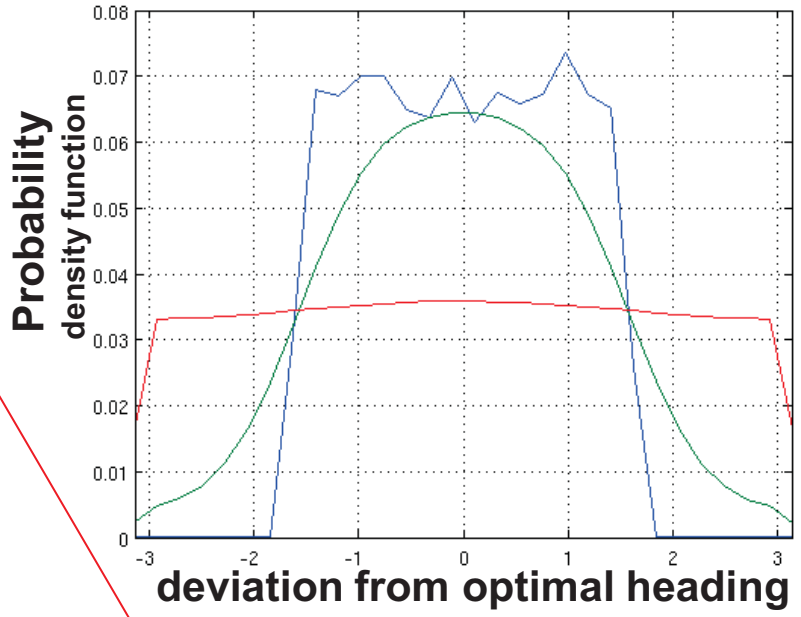
$$A(x) = sgn\left(\frac{dx}{dt}\right) \quad f(u) = \frac{u}{\|u\|}$$

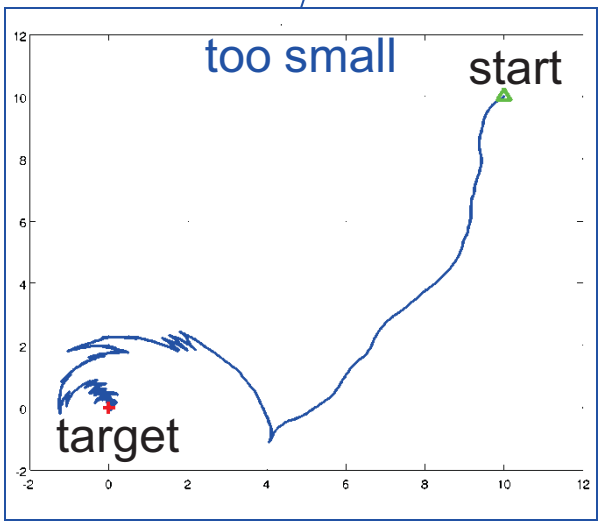
Intuitive meaning:
If the conditions improved
→use the motor command as a bias
otherwise
→ reverse it

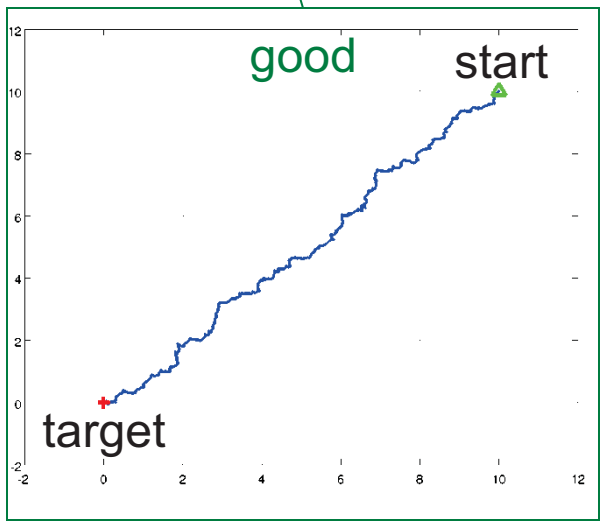
u control input (motor velocities)
η random variable
x sensory information (state)

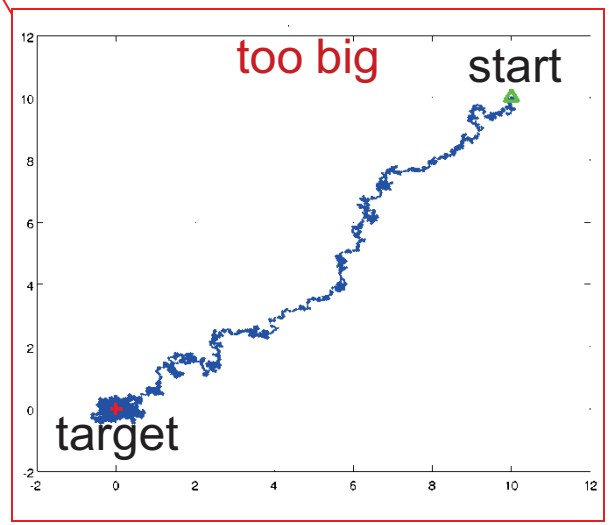
Performance increase by random perturbations





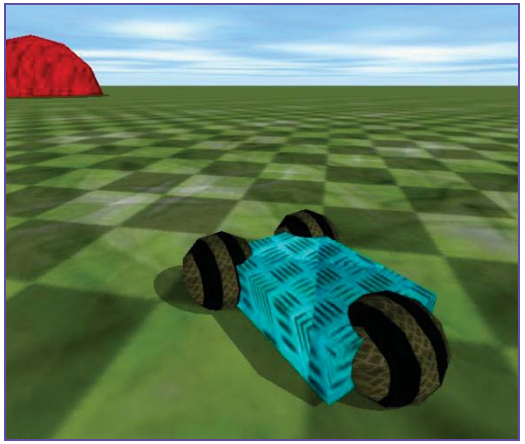






Robustness to hardware damages

Experimental setup

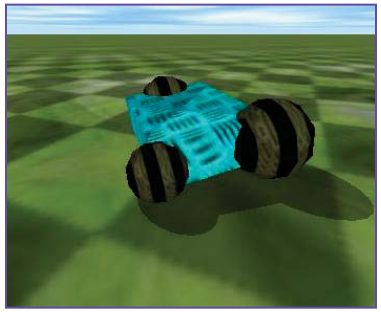


Robot: simulated mobile robot with two independent wheels and an omnidirectional camera

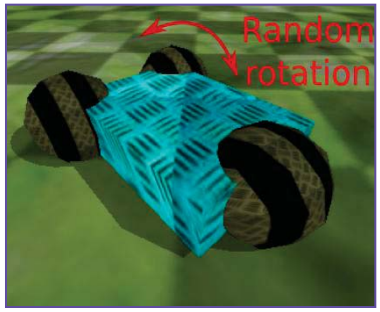
Task: reach a red hemisphere

Sensory information: number of red pixels in the camera image

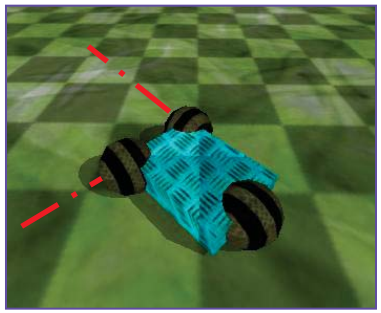
4 simulated hardware faults



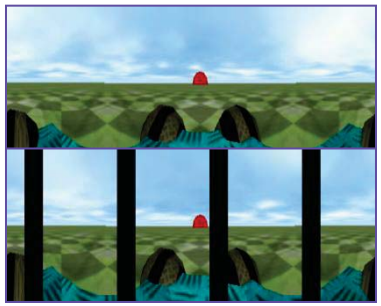
Change in the size of a wheel



Uncontrollability of a wheel

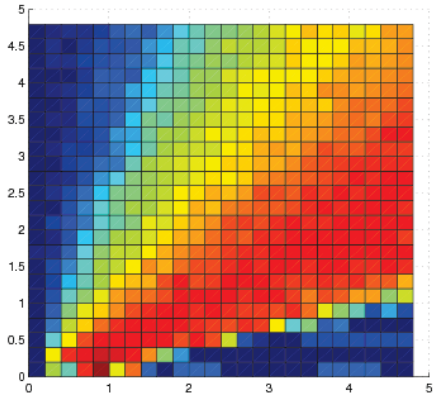


Change of the rotation axis of a wheel

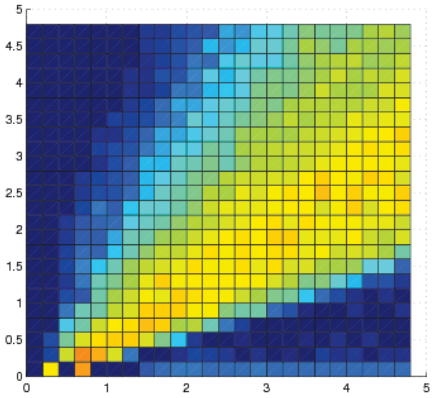


Obscuration of 20% of the camera

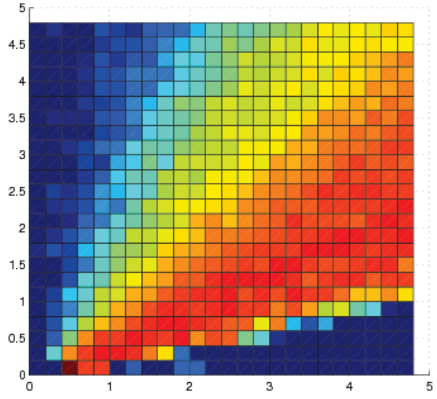
Results



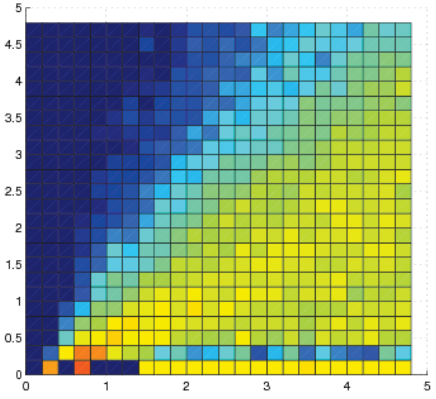
No damage



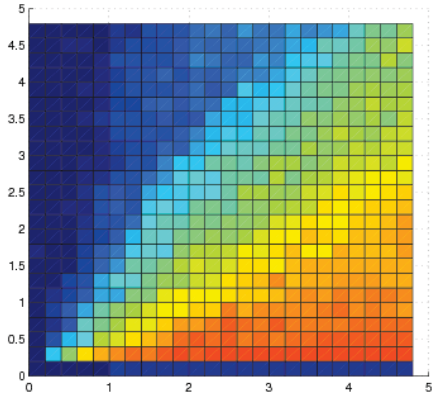
Reduced wheel size



Camera damage



Axle rotation



Uncontrollable wheel

X axis: bias coefficient
Y axis: perturbation coefficient
Color: performance

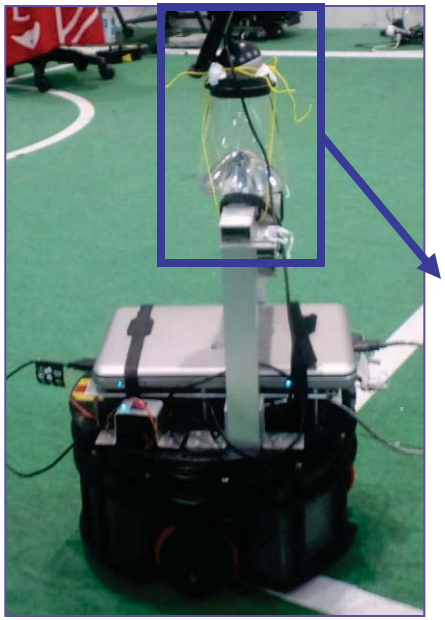
Low **High**
(time spent touching the target)

- The robot is able to reach the target in all the cases
- An optimal ratio between the noise and the signal exists
- The optimal ratio depends on the hardware and environment

Sensor noise robustness

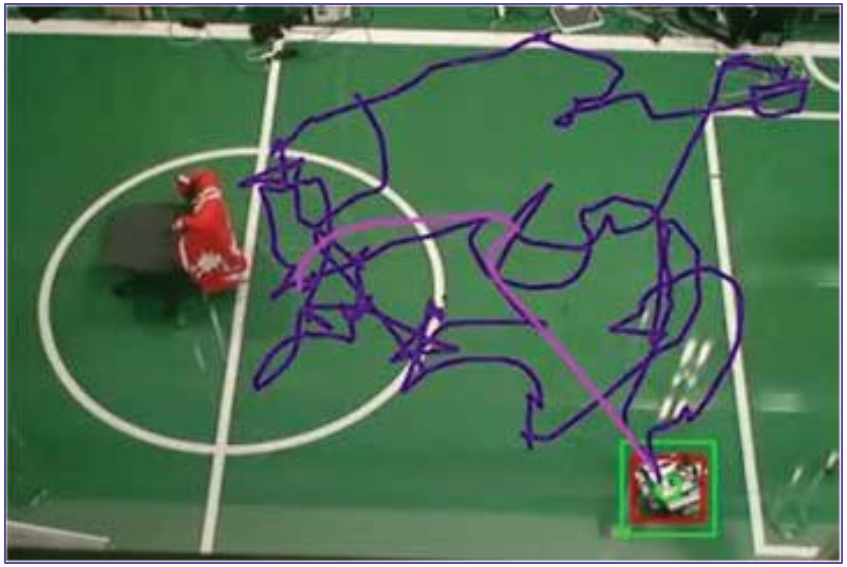
Experimental setup

Robot: real mobile robot equipped with an omnidirectional camera
Task: Reach a red blanket
Sensory information: Number of red pixels in the camera image



B12 mobile robot

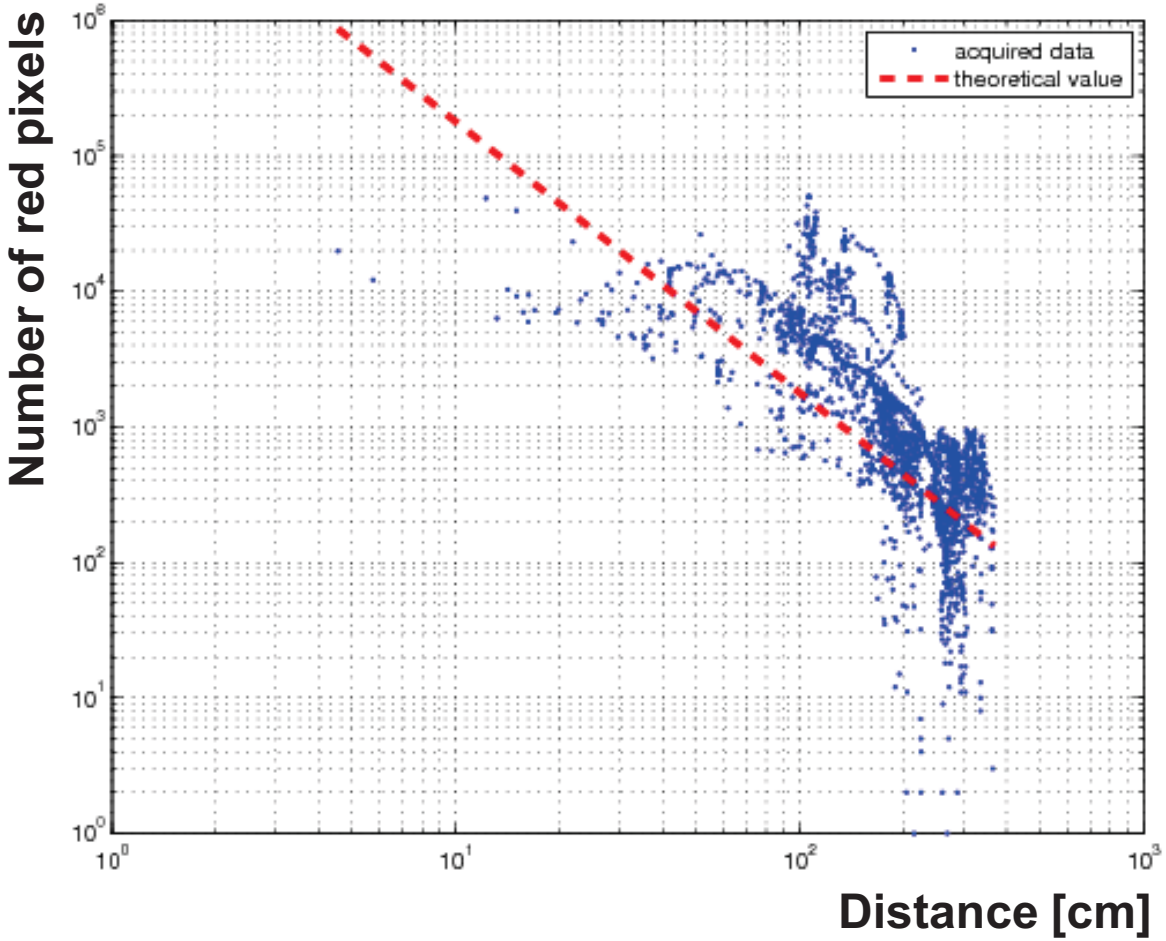
Omnidirectional camera



Reaching in a real environment

Results

- The robot is able to reach the target even given the really noisy input information
  - Can be used for real world problems



Conclusions

- Biased random walk is a very robust control method when applied in the control space
- Verified in a target reaching task
  - Robust to hardware damages
  - Robust to sensor noise
- The performance depends just on the ratio of the two scaling factors α and β
  - The ratio is different for different hardware conditions

Future works

- Automatically determine the optimal α/β ratio
  - Preliminary results in *F. DallaLibera, S. Ikemoto, T. Minato and H. Ishiguro and E. Menegatti,Robot control inspired by Escherichia Coli chemotaxis, ROBOMEC 2010*
- Verify whether the perturbation distribution influences the results
- Extend the approach to target reaching with obstacle avoidance

Thank you