A parameterless biologically inspired control algorithm robust to nonlinearities, dead-times and low-pass filtering effects

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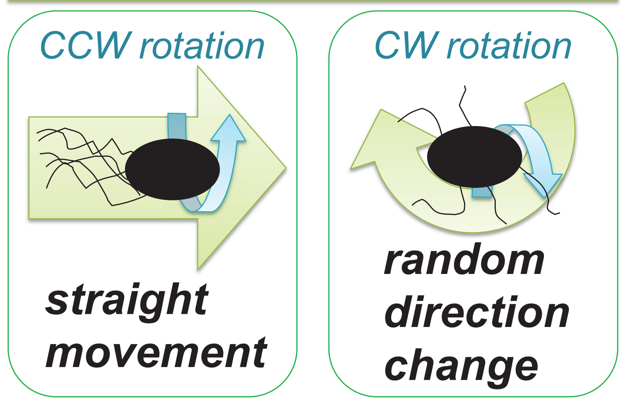
Abstract

An algorithm for robot control inspired by Escherichia Coli chemotaxis is presented. A model that explains the performance increase due to introduction of random perturbations is provided and used to derive a completely adaptive and parameterless algorithm. Practical applicability is shown by a mobile robot navigation task in which the robot structure is unknown and the robot undergoes hardware damages.

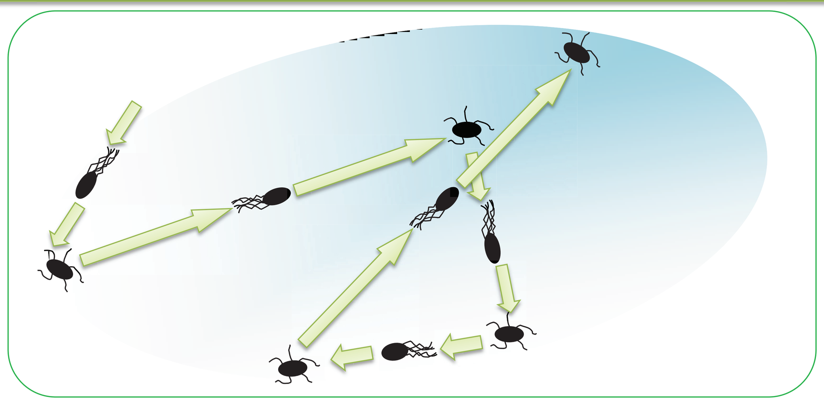
Related works

Escherichia Coli proceeds by alternating two movements



If the conditions improve: longer straight movements = less random changes

Biased random walk toward food sources



Robots with similar strategy [2]

Proceed by alternating two behaviors:
- Straight movement
- Random rotation

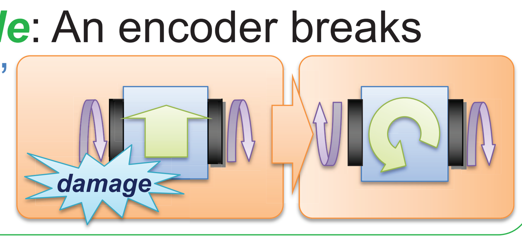
Advantages
- Robust to noise
- Do not stuck in local minima
- Robots distribute among multiple sources

Problem

The robot may not reach the target due to hardware faults

Example: An encoder breaks

"go forward" becomes "spinning"



Advanced fault detection and recovery techniques [3,4]

Require precise identification of possible faults or very high computational power

Proposed approach **Biased random walk directly in the command space**
- Extreme simplicity
- Appropriate behaviors that exploit the working hardware are found

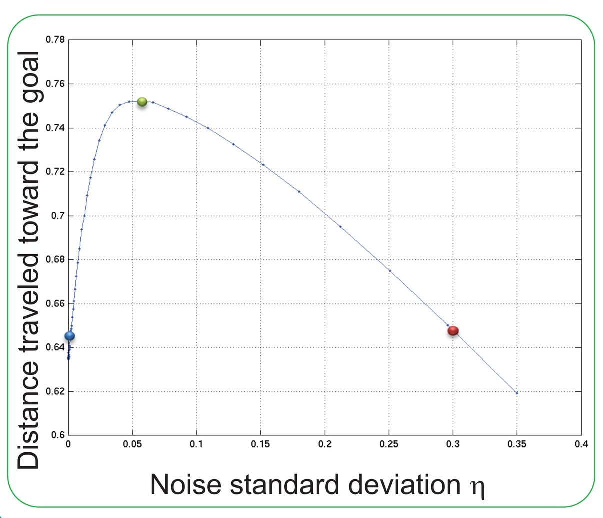
Control algorithm

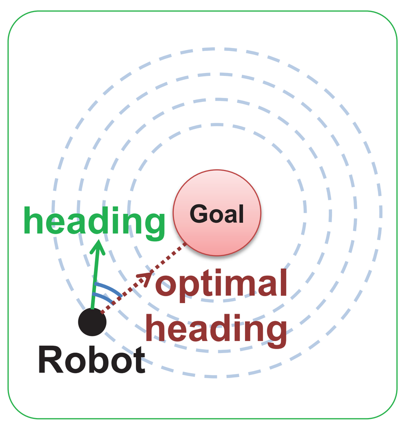
If the conditions improved (e.g. got closer to the goal) then keep the previous motor command but add a random perturbation to it else choose randomly a new motor command

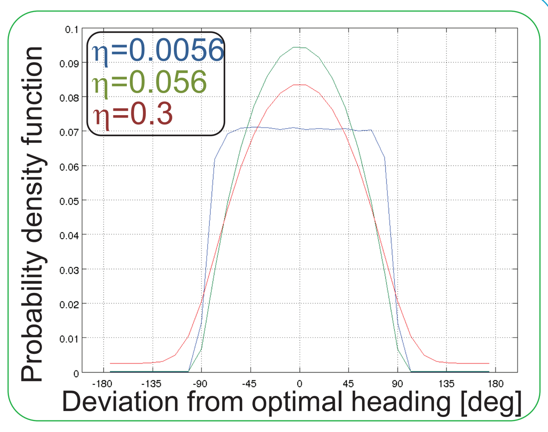
Adding random perturbations of opportune magnitude to the control input **improves the performance**

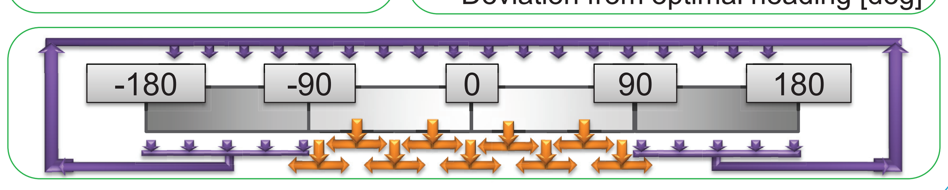
$$u^i_{t+1} = \begin{cases} u^i_t + \eta^i_t R & if\ \Delta A_t \geq 0 \\ random\ selection & otherwise \end{cases}$$

***Example:* 2D case**

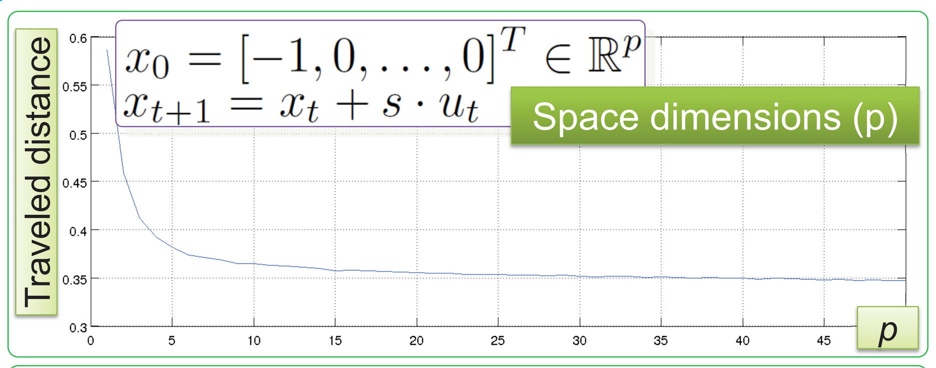






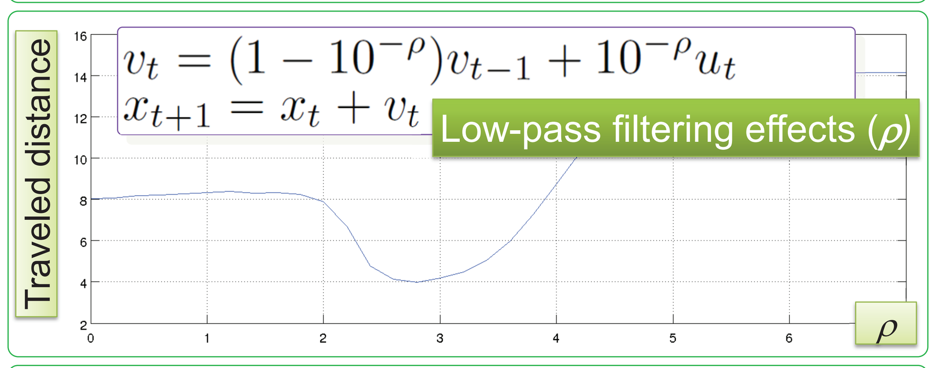


Performance measurements



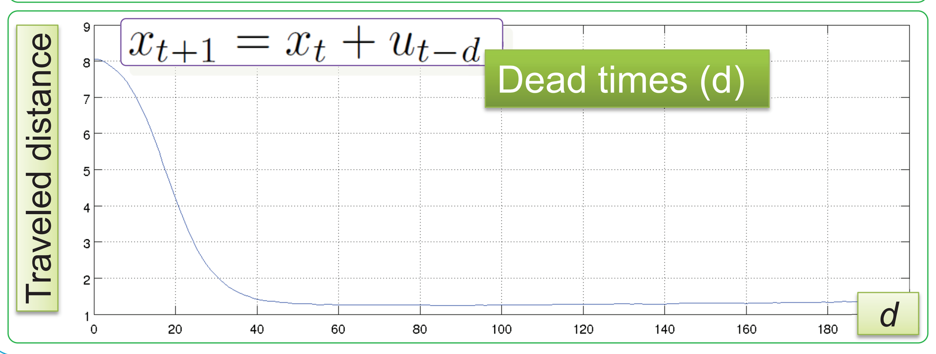
$x_0 = [-1, 0, \dots, 0]^T \in \mathbb{R}^p$

$x_{t+1} = x_t + s \cdot u_t$



$v_t = (1 - 10^{-\rho})v_{t-1} + 10^{-\rho} u_t$

$x_{t+1} = x_t + v_t$

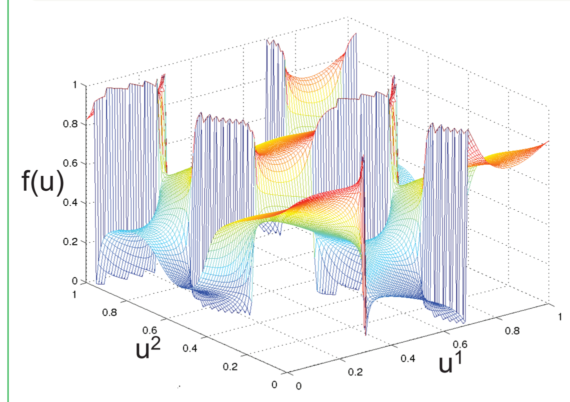


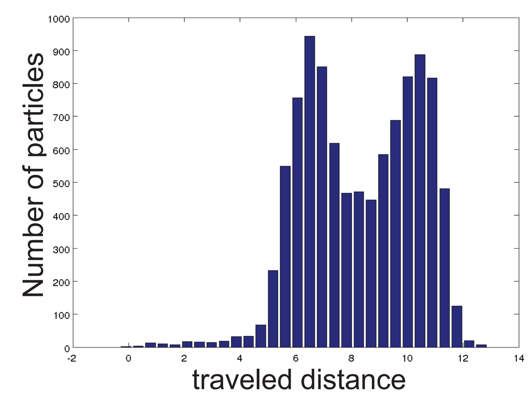
$x_{t+1} = x_t + u_{t-d}$

System nonlinearites

$x^i_{t+1} = x^i_t + s \cdot f^i(u_t)$

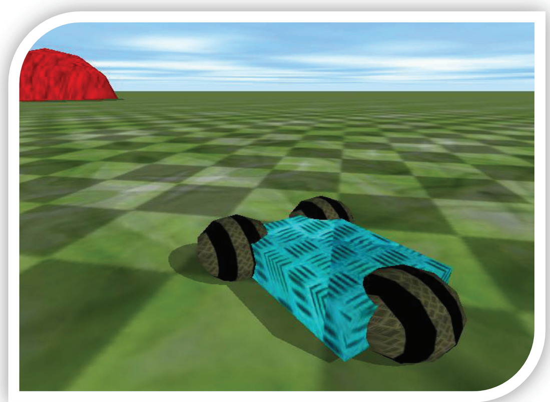
$f^i(u) = \frac{1}{\pi}\arctan\left(\frac{(\sin(2\pi u + \xi^i))^T Q^i \sin(2\pi u + \xi^i)}{(\sin(2\pi u + \zeta^i))^T P^i \sin(2\pi u + \zeta^i)}\right)$





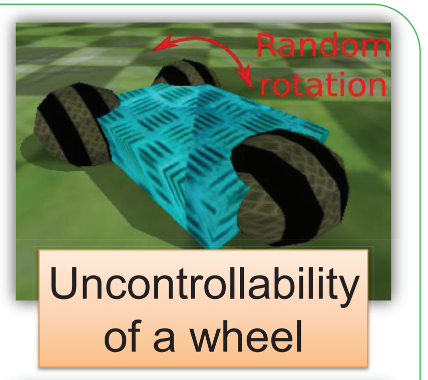
Experiment

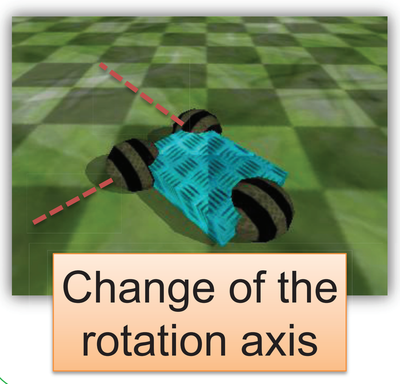
Setup

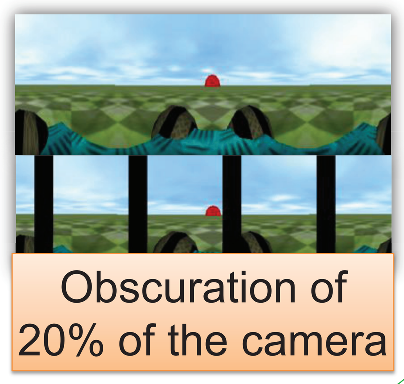


Robot: simulated mobile robot with two independent wheels
Sensory information: number of red pixels in a simulated omnidirectional camera
Task: reach a red hemisphere

Simulated four damages







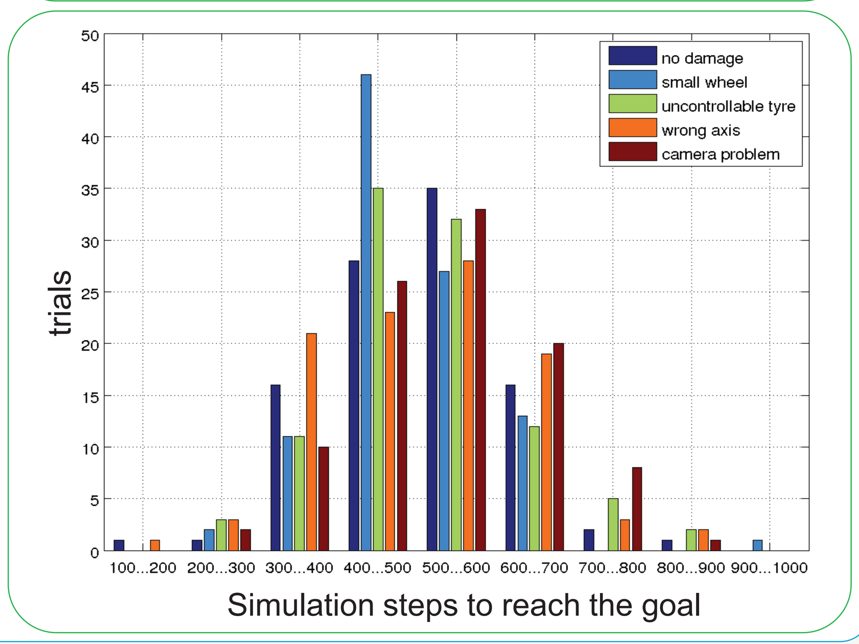
Automatic noise adaptation based on the estimation of the motor command variance

$\delta^i_0 = 1.1$

$\sigma^i_t = \frac{(u^i_t - u^i_{t-1})^2}{2}$

$\delta^i_{t+1} = \begin{cases} 1/\delta^i_t & if\ t\ odd \wedge \sigma^i_t \geq \sigma^i_{t-2} \\ \delta^i_t & otherwise \end{cases}$

$\eta^i_{t+1} = \begin{cases} \eta^i_t \delta^i_{t+1} & if\ t\ odd \\ \eta^i_t & otherwise \end{cases}$



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[4] Bongard, J., Zykov, V. and Lipson, H. "Resilient machines through continuous self-modeling", Science, vol. 314 (5802), pp. 1118–1121, 2006.