Control of Locomotion in Modular Robotics

Master Project

Jérôme Maye

Biologically Inspired Robotics Group
School of Computer and Communication Sciences
Ecole Polytechnique Fédérale de Lausanne

March 8, 2007

BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Outline

BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

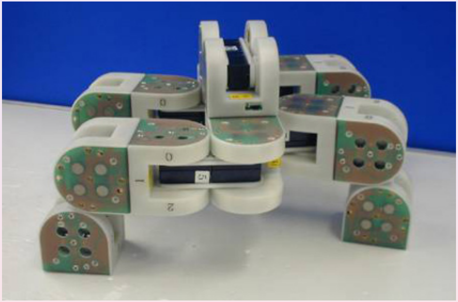
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Outline

Modular Robotics Characteristics

A modular robot is constructed out of multiple homogeneous building blocks with:

- at least one actuated degree of freedom
- a (dynamic) connection mechanism
- computational power
- optional sensing abilities
- communication abilities
- electrical power



BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Modular Robotics Promises and Applications

Compared to "classical" robots:

- robustness
- adaptiveness
- self-repair
- economy

BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

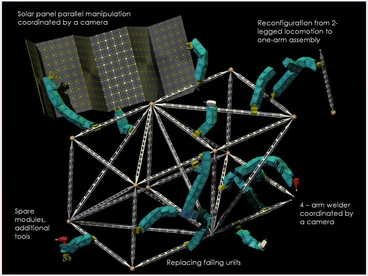
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Modular Robotics Promises and Applications

Compared to "classical" robots:

- robustness
- adaptiveness
- self-repair
- economy

Space Missions



BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Modular Robotics Promises and Applications

Compared to "classical" robots:

- robustness
- adaptiveness
- self-repair
- economy

Urban Search and Rescue

BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

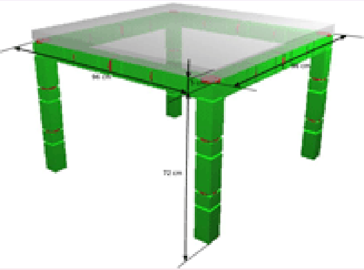
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Modular Robotics Promises and Applications

Compared to "classical" robots:

- robustness
- adaptiveness
- self-repair
- economy

Adaptive Furniture



BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Modular Robotics Locomotion

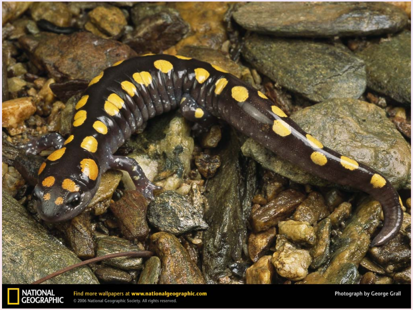
- Locomotion is one of the key requirements
- Coordination of multiple actuated joints
- Bio-inspired Central Pattern Generator (CPG) approach is appealing
- A CPG is a network of neurons able to generate coordinated rhythmic activity

BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Modular Robotics Locomotion

- Locomotion is one of the key requirements
- Coordination of multiple actuated joints
- Bio-inspired Central Pattern Generator (CPG) approach is appealing
- A CPG is a network of neurons able to generate coordinated rhythmic activity



BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Outline

1. Motivation
   - Challenges of Locomotion in Modular Robotics
   - Preliminary Work
2. Our Contribution/Results
   - Implementation of the Experimental Setup
   - Experiments

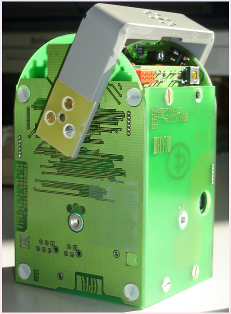
BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

YaMoR Robot

Module

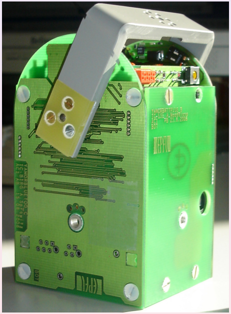
YaMoR Robot

Module

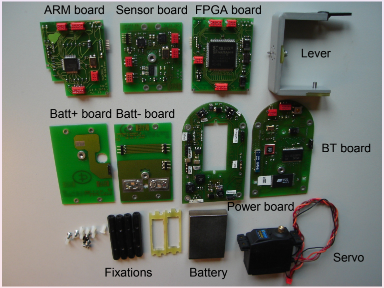


YaMoR Robot

Module



Components

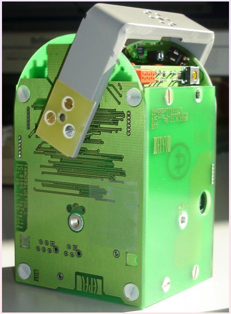


BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

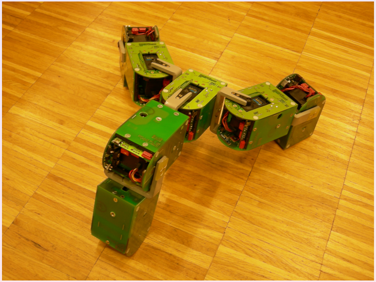
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

YaMoR Robot

Module



Robot Example



BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

CPG Design

$$\dot{\phi}_i = \omega_i + \sum_j (\omega_{ij} r_j sin(\phi_j - \phi_i - \varphi_{ij})$$

$$\ddot{r}_i = a_r(\frac{a_r}{4}(R_i - r_i) - \dot{r}_i)$$

$$\ddot{x}_i = a_x(\frac{a_x}{4}(X_i - x_i) - \dot{x}_i)$$

$$\theta_i = x_i + r_i cos(\phi_i)$$

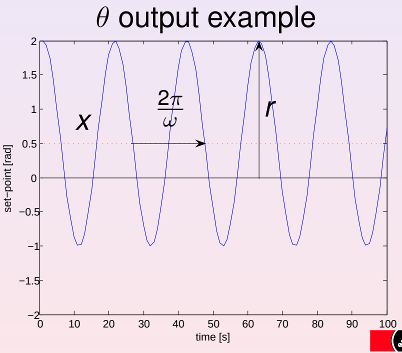
CPG Design

$$\dot{\phi}_i = \omega_i + \sum_j (\omega_{ij} r_j sin(\phi_j - \phi_i - \varphi_{ij})$$

$$\ddot{r}_i = a_r(\frac{a_r}{4}(R_i - r_i) - \dot{r}_i)$$

$$\ddot{x}_i = a_x(\frac{a_x}{4}(X_i - x_i) - \dot{x}_i)$$

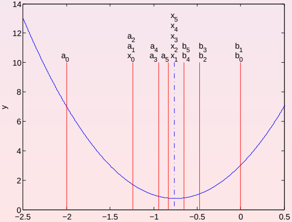
$$\theta_i = x_i + r_i cos(\phi_i)$$



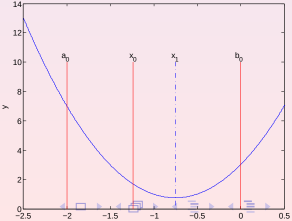
Learning Algorithm - Powell's Method

- Simple heuristic that has shown interesting results in simulation
- Repeated one-dimensional minimizations along a constantly updated direction set
- One-dimensional minimization with Brent's method
- Powell's method changes the direction set depending on the function

Golden Section

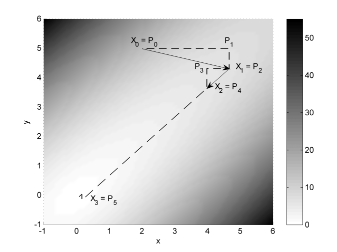


Parabolic Interpolation



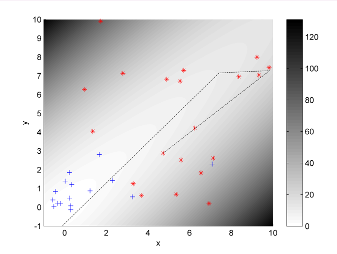
Learning Algorithm - Powell's Method

- Simple heuristic that has shown interesting results in simulation
- Repeated one-dimensional minimizations along a constantly updated direction set
- One-dimensional minimization with Brent's method
- Powell's method changes the direction set depending on the function



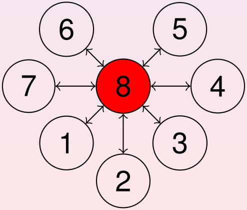
Learning Algorithm - Particle Swarm Optimization

- Stochastic optimization method inspired by the movement of flocking birds
- A set of particles spreaded in a virtual space fly towards the optimum of the function
- New position of a particle depends on its best performance and the best performance of its neighborhood



YaMoR Communication Protocol

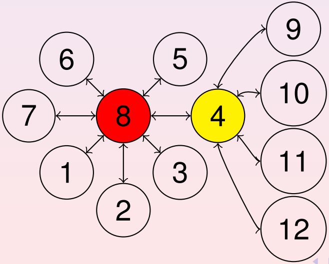
- Original software delivered with the Bluetooth chip lacks the features needed to implement the CPG model
- Scatternet protocol built on top of it allows easy intermodule communication
- After initial network configuration, packets are simply launched in the network
- Transparent communication



BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

YaMoR Communication Protocol

- Original software delivered with the Bluetooth chip lacks the features needed to implement the CPG model
- Scatternet protocol built on top of it allows easy intermodule communication
- After initial network configuration, packets are simply launched in the network
- Transparent communication

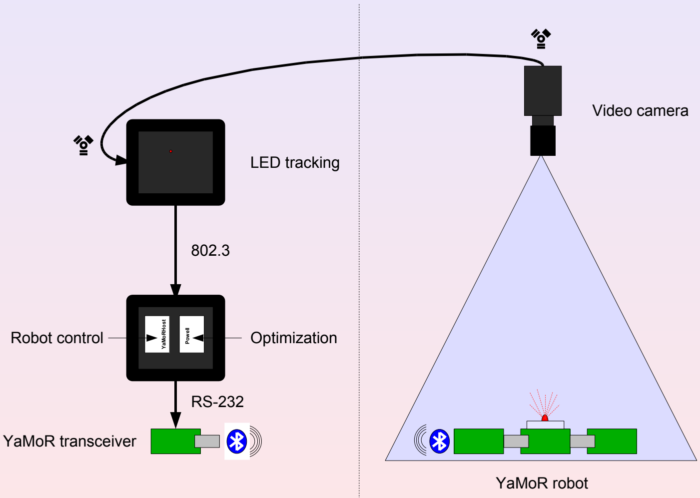


Outline

BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

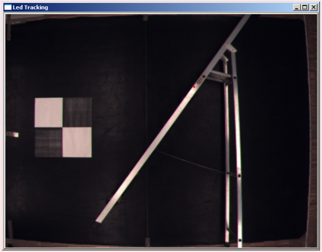
Experimental Setup Overview



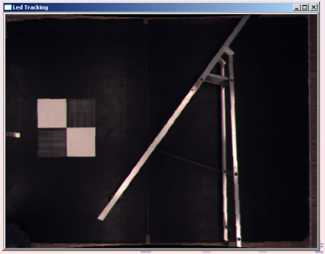
LED Tracking

- Application running on a dedicated PC
- Provides the position of the LED to a remote PC each 39 ms on average
- Highest quantity of white pixels in a moving window
- Correction function applied on the remote PC

Original Image



Corrected Image



Optimization Algorithms

- Implemented on a remote PC
- Function to minimize is given as:

$$f(\vec{x}) = \frac{1}{avg\_speed + 1}$$

- $\vec{x}$ contains values for the parameters under optimization
- *avg_speed* is computed as the displacement of the LED during 8 seconds, over the time between the two measurements
- All the parameters are limited in the range $[0, 1]$

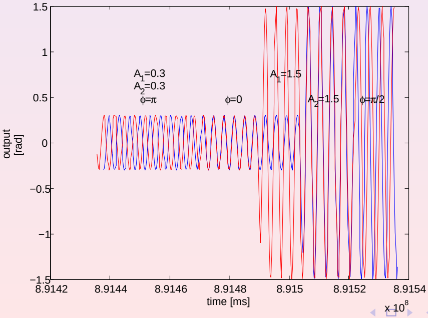
Robot Control

- Remote PC connected to a spare Bluetooth device via serial port
- Commands are sent to the modules, using the Scatternet protocol
- Scatternet protocol limitations:
  - Initial network structure

  - Broadcast and inter-message time

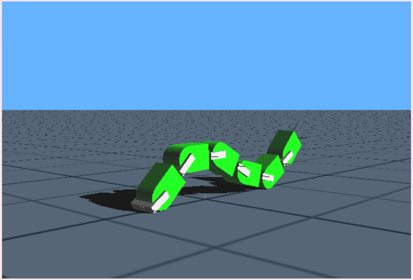
CPG Implementation

- An oscillator runs in each module
- Its output controls the position of the servo via a PWM
- An oscillator can be coupled with up to 3 neighbors
- A module periodically receives/sends state variables from/to the neighbors it is coupled



Simulation Environment

- All the experimental setup has been reproduced in Webots
- Nearly the same code is used
- Possibility to have simulated and real experiments in parallel
- Ideal substrate for testing new robots or doing systematic experiments

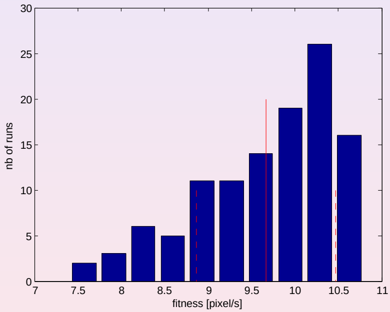


BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Outline

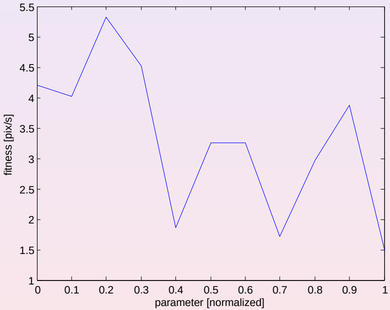
Preliminary - Noise on Fitness Evaluation

- For the same set of parameters, different fitness evaluations
- Non linearity in the movement of the robot
- Irregularity of the ground

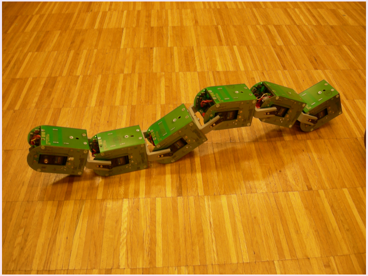


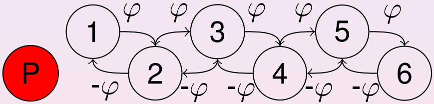
Preliminary - Fitness Example in 1 Dimension

- Several possible local optima for a single parameter when the others are fixed
- Wide exploration required to find the best one
- Even if a local optimum is found for a parameter, the others often adapt to generate a new efficient gait

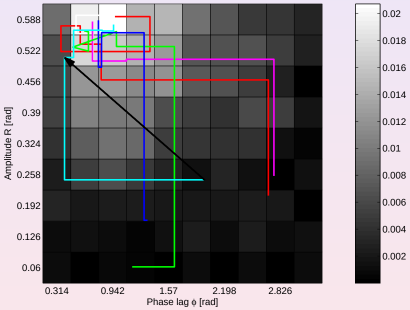


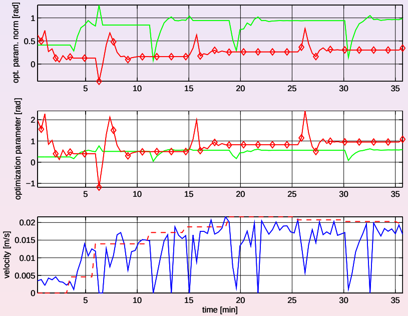
Snake Robot - Configuration



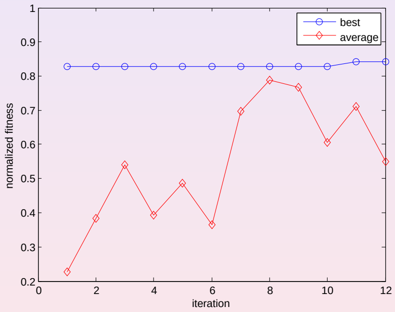


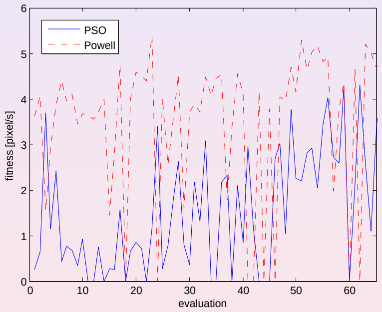
Snake Robot - Powell's Method



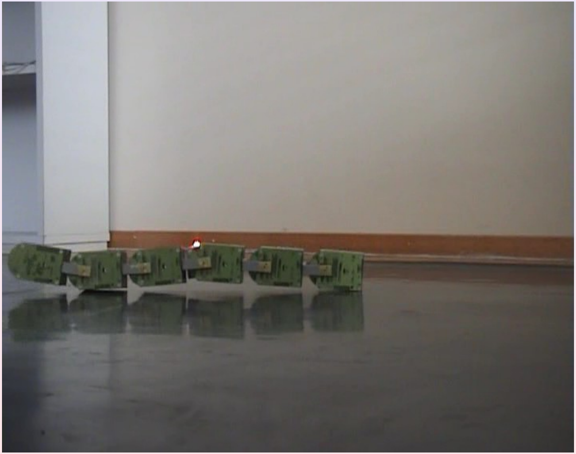


Snake Robot - Particle Swarm Optimization

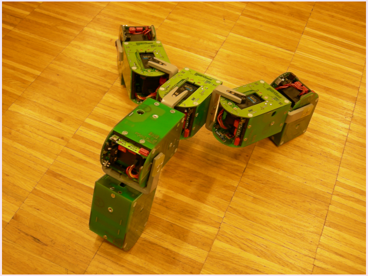


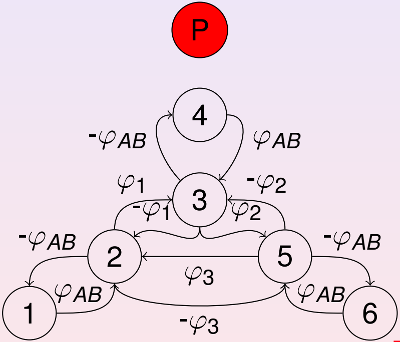


Snake Robot - Movie

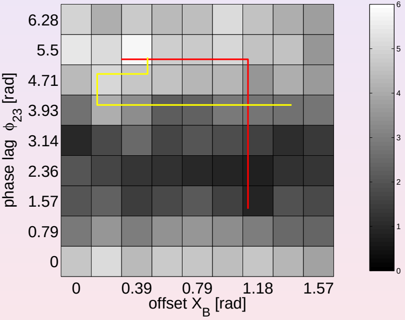


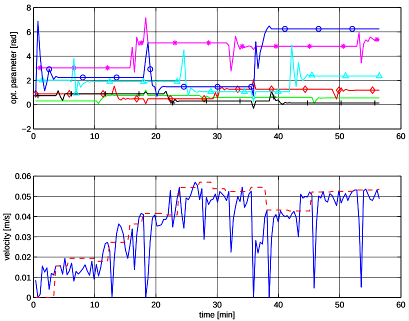
Tripod Robot - Configuration



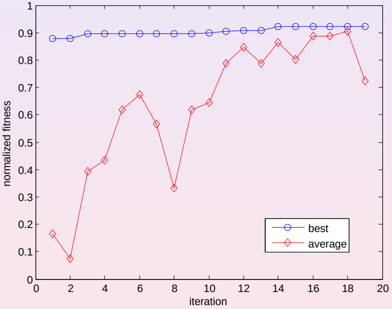


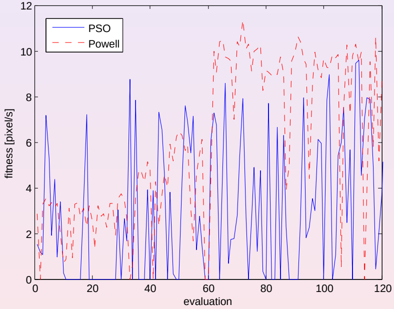
Tripod Robot - Powell's Method





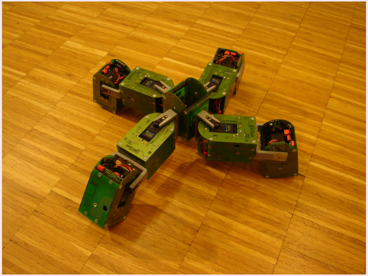
Tripod Robot - Particle Swarm Optimization

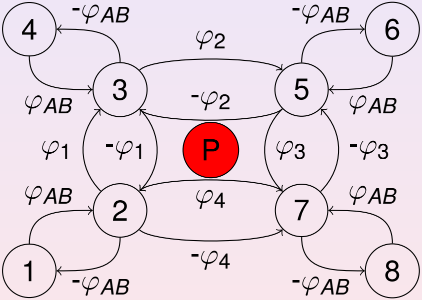




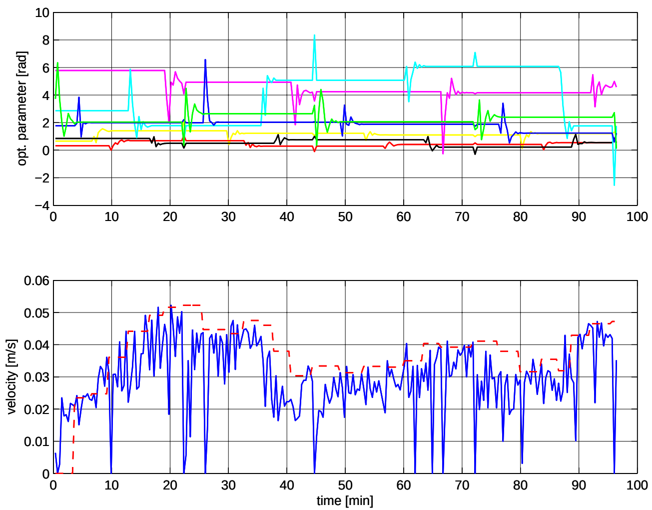
Tripod Robot - Movie

Quadruped Robot - Configuration

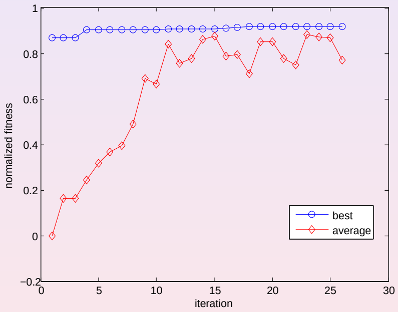


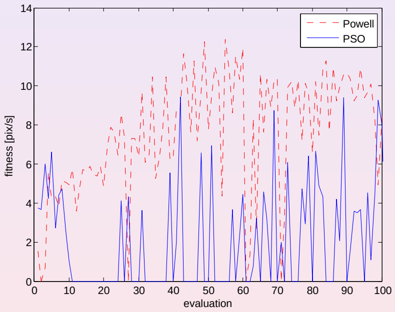


Quadruped Robot - Powell's Method



Quadruped Robot - Particle Swarm Optimization





Quadruped Robot - Movie

Summary

- Building of a complete distributed system, with software running on different platforms
- Validation of the previous simulations with Powell's method
- Comparison with Particle Swarm Optimization

- Outlook
  - Long-life learning
  - Control of direction