Control of Locomotion in Modular Robotics
Master Project

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1. Motivation
   - Challenges of Locomotion in Modular Robotics
   - Preliminary Work

2. Our Contribution/Results
   - Implementation of the Experimental Setup
   - Experiments
Outline

1 Motivation
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2 Our Contribution/Results
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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
Modular Robotics Promises and Applications

Compared to "classical" robots:

- robustness
- adaptiveness
- self-repair
- economy
Modular Robotics Promises and Applications

Compared to "classical" robots:
- robustness
- adaptiveness
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- economy

Space Missions
Modular Robotics Promises and Applications

Compared to "classical" robots:
- robustness
- adaptiveness
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- economy

Urban Search and Rescue
Modular Robotics Promises and Applications

Compared to "classical" robots:

- robustness
- adaptiveness
- self-repair
- economy

Adaptive Furniture
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
Modular Robotics Locomotion

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YaMoR Robot

Module

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Control of Locomotion in Modular Robotics
YaMoR Robot Module

Control of Locomotion in Modular Robotics
YaMoR Robot

Module

Components

ARM board  Sensor board  FPGA board

Lever

Batt+ board  Batt- board

BT board

Power board

Fixations  Battery  Servo

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YaMoR Robot

Module

Robot Example

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Control of Locomotion in Modular Robotics
CPG Design

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

\[
\ddot{r}_i = a_r \left( \frac{a_r}{4} (R_i - r_i) - \dot{r}_i \right)
\]

\[
\ddot{x}_i = a_x \left( \frac{a_x}{4} (X_i - x_i) - \dot{x}_i \right)
\]

\[
\theta_i = x_i + r_i \cos(\phi_i)
\]
**CPG Design**

\[
\dot{\phi}_i = \omega_i + \sum_j (\omega_{ij} r_j \sin(\phi_j - \phi_i - \varphi_{ij})) \\
\ddot{r}_i = a_r \left( \frac{a_r}{4} (R_i - r_i) - \dot{r}_i \right) \\
\ddot{x}_i = a_x \left( \frac{a_x}{4} (X_i - x_i) - \dot{x}_i \right) \\
\theta_i = x_i + r_i \cos(\phi_i)
\]
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

Graph showing multiple points labeled as $X_0 = P_2$, $P_1$, $P_3$, $X_1 = P_2$, $X_2 = P_4$, and $X_3 = P_5$.
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
YaMoR Communication Protocol

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Experimental Setup Overview

- YaMoRHost
- Powell
- LED tracking
- Video camera
- YaMoR robot
- YaMoR transceiver
- Robot control
- Optimization
- 802.3
- RS-232

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Control of Locomotion in Modular Robotics

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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:

\[
    f(\vec{x}) = \frac{1}{\text{avg\_speed} + 1}
\]

- \(\vec{x}\) contains values for the parameters under optimization
- \text{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
    
    1  2  3  4  5  6  7
  
  - Broadcast and inter-message time
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
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For the same set of parameters, different fitness evaluations

- Non linearity in the movement of the robot
- Irregularity of the ground
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

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Snake Robot - Particle Swarm Optimization

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Control of Locomotion in Modular Robotics
Snake Robot - Movie
Motivation

Our Contribution/Results

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Tripod Robot - Configuration

\[
\begin{align*}
\phi_1 - \phi_{AB} - \phi_2 - \phi_{AB} \\
\phi_{AB} - \phi_{AB} - \phi_3 - \phi_{AB}
\end{align*}
\]
Tripod Robot - Powell’s Method

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Tripod Robot - Particle Swarm Optimization

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Control of Locomotion in Modular Robotics
Tripod Robot - Movie
Quadruped Robot - Configuration

![Image of quadruped robot configuration]

Diagram showing the configuration of the quadruped robot with labeled parts and angles. The diagram includes nodes labeled 1 to 8 with connections indicating the movement angles (φ) and AB angles.
Quadruped Robot - Powell’s Method

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Control of Locomotion in Modular Robotics
Quadruped Robot - Particle Swarm Optimization

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Quadruped Robot - Particle Swarm Optimization

- Normalized fitness over iteration
- Fitness [pix/s] over evaluation
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