Online Adaptation of Locomotion Control to Changes in Body Structure

Michka Mélo

Biorobotics Laboratory, STI, EPFL
Supervisors: Rico Möckel, Soha Pouya, Stéphane Bonardi
Prof. Auke Jan Ijspeert
Motivation

Improve the robot locomotion by making it aware of its body.

Allow injured robots to keep moving.
Outline

• Robotic Platform, Tools and Strategy
• Functional Graph Representation
• Automatic Network Generator
• Similarity Measure
• Strategy Validation
Roombots

- Reconfigurable robots for adaptative furniture.

- At the module level:
  - Three degrees of freedom
  - Ten connectors

- At the metamodule level:
  - Four connection types.

A piece of adaptative furniture [Sproewitz, 2010]
Locomotion control and optimization

• Locomotion is controlled by **Central Pattern Generator (CPG)**
  • Network of coupled phase oscillators
  • One oscillator per degree of freedom
  • Servo inputs derived from state variables of CPG

• Evolution of CPG parameters using **Particle Swarm Optimization (PSO)**
  • Population-based optimization method based on cooperation
  • Fitness computed from locomotion velocity

This is implemented in the Biorob Optimization Framework by Jesse van den Kieboom.
Tools

Robot Structure Analyzer

Limb/Body Finder

Symmetry Finder

Similarity Finder

Rules

CPG Network Design Tool

CPG Topology

CPG Parameters
Graph Representation

CPG Network

Topology

Parameters

Robot

Graph Representation

Search Table

Optimization

Webots files provided by Soha Pouya.

\[
\begin{array}{c|c}
R_i & X_i \\
\hline
i=1 & \\
\vdots & \\
i=n & \\
\end{array}
\]

\[
\begin{array}{c|c|c}
\psi_{ij} & i=1 & \ldots & i=n \\
\hline
j=1 & \\
\vdots & \\
j=n & \\
\end{array}
\]

Similarity Measure
Functional Symmetry

Extract symmetry information relevant in terms of locomotion.

Quadruped, Five modules, PER connection type (Quad5_PER)  Quadruped, Six modules, PAR connection types (Quad6_PAR)
Geometrical Graph Representation

Quad5_PER

Quad6_PAR

Missing symmetries
Functional Graph Representation

Quad5.PER

Quad6.PAR

Symmetry groups expected
Automatic CPG Network Generator

- Easier offline design.
- Crucial for online optimization!
Bio-inspired articulation network

Quad5_PER

Quad6_PAR

CPG Studio view of CPG networks.
## Selection and Coupling Rules

<table>
<thead>
<tr>
<th>Type</th>
<th>Selection rules</th>
<th>Coupling rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hips (s₁,s₂)</td>
<td>Limb/body interface</td>
<td>Fully interconnected</td>
</tr>
<tr>
<td></td>
<td>Control only one limb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Most Proximal</td>
<td></td>
</tr>
<tr>
<td>Knees (s₁,s₂)</td>
<td>Center of limb</td>
<td>Coupled with corresponding hip</td>
</tr>
<tr>
<td>Spines (s₁, s₂, m₁)</td>
<td>Linear parts of body</td>
<td>Coupled with neighbouring hips and spines nodes.</td>
</tr>
</tbody>
</table>
Bio-inspired articulation network
Performance of articulation network

Quad5_PER

<table>
<thead>
<tr>
<th>Articulation Network</th>
<th>Number of</th>
<th>Complete Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Active Servos</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>Open Parameters</td>
<td>44</td>
</tr>
</tbody>
</table>

How faster is the articulation network optimized?
Are the gaits obtained efficient?
Performance of articulation network

Some parameters of the experiment have to be adjusted.
Graph Representation

Topology

Parameters

$R_i$

$X_i$

$\psi_{ij}$

$\psi_{ij}$

$R_i$ $X_i$

$\begin{array}{ccc}
  i=1 & \ldots & i=n \\
  \vdots & \ddots & \vdots \\
  i=n & \ldots & j=n \\
\end{array}$

Search Table

Robot

Optimization

CPG Network

Similarity Measure

Graph Representation

CPG Network

<table>
<thead>
<tr>
<th>Graph Representation</th>
<th>CPG Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topology</td>
<td>Parameters</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

18
Similarity Measure

Integrate information from existing tools.

Graph representation $\rightarrow$ Number of modules $\rightarrow$ Difficult to interpret

Limb/Body finder $\rightarrow$ Number of limbs

Symmetry finder $\rightarrow$ Symmetry groups

Symmetric limbs Articulations information
Graph Representation

CPG Network

Topology

Parameters

Robot

Graph Representation

Search Table

Similarity Measure

Optimization

$\psi_{ij}$

<table>
<thead>
<tr>
<th>i=1</th>
<th>...</th>
<th>i=n</th>
</tr>
</thead>
<tbody>
<tr>
<td>j=1</td>
<td>...</td>
<td>j=n</td>
</tr>
</tbody>
</table>

Parameters

<table>
<thead>
<tr>
<th>Ri</th>
<th>Xi</th>
</tr>
</thead>
<tbody>
<tr>
<td>i=1</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>i=n</td>
<td></td>
</tr>
</tbody>
</table>
Strategy Validation

Quad6_PAR

One run
Random initialization of open parameters.

Tripod, Five Modules (Tri5)

Two runs
Random initialization of open parameters.
Selection of parameters values from Quad6_PAR for initialization

Is the optimization faster with selected parameters values?
Does optimization with selected parameters values lead to efficient gaits?
Strategy Validation

Best fitness evolution over generations

Only one run!

Random initialization

Selected values for initialization (±10% around parameters values extracted from Quad6_PAR)
Strategy Validation

• ± 10 % : too wide?
  – Narrow the fork (± 5 % ?)
  – Gaussian distribution

• Similarity : still to explore...

Tri5, Random initialization values (velocity : 0.684)
Tri5, Selected initialization values (velocity : 0.761)
Quad6_PAR, random initialization values (velocity : 0.455)

Webots Movies
Graph Representation

CPG Network

Topology

Parameters

\[ \psi_{ij} \]

<table>
<thead>
<tr>
<th>( i )</th>
<th>( X_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( i=1 )</td>
<td></td>
</tr>
<tr>
<td>( \ldots )</td>
<td></td>
</tr>
<tr>
<td>( i=n )</td>
<td></td>
</tr>
</tbody>
</table>

Search Table

Optimization

Robot

Graph Representation

Similarity Measure

\[ \text{Similarity Measure} \]

<table>
<thead>
<tr>
<th>Graph Representation</th>
<th>CPG Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \ldots )</td>
<td>( \ldots )</td>
</tr>
</tbody>
</table>
References

• (1) http://www.nature.com/nrn/journal/v6/n6/images/nrn1686-f1.jpg
• (2) http://rpmedia.ask.com/ts?u=/wikipedia/commons/thumb/9/92/Sort_sol_pdfnet.jpg/140px-Sort_sol_pdfnet.jpg
• (3) http://www.gamasutra.com/features/20051213/figure2.gif


• Mikaël Mayer, Roombots Modules : Kinematics Considerations for Moving Optimizations, Semester project report, 2009.

• For more information on this project : M. Mélo, Online Optimization of Locomotion Control to Changes in Body Structure, Semester project report, 2011.