Locomotion Capabilities of a Modular Robot with Eight Pitch-Yaw-Connecting Modules

J. Gonzalez-Gomez, E. Boemo  
DSLabs, School of Engineering,  
Universidad Autonoma de Madrid, Spain

H. Zhang, J. Zhang  
TAMS, Department of Informatics,  
University of Hamburg, Germany

Clawar 2006  
9th International Conference on Climbing and Walking Robots.  
12-14 September. Brussels, Belgium
Outline

• Modular robotics
• Previous work
• Overview of the pitch-yaw-connecting robot
• Control approach
• Locomotion capabilities
• Videos
• Conclusion
• Future work
Modular Robotics (I)

- Main idea: Building robots composed of **modules**
- The design is focused in the module, not in a particular robot
- The different combinations of modules are called **configurations**

- **Some Advantages:**
  - Versatility
  - Fast prototyping
  - Testing new ideas

Very good platforms for researching in locomotion
Modular Robotics (II)

- The idea of modular robotics was introduced by Mark Yim, in 1994
- There are many groups working on this topic in the world.
- The most advanced robots are:
  - POLYBOT (USA). Palo Alto Research Center (PARC)
  - M-TRAN (JAPAN). Advance Industrial Science Technology (AIST)
  - YAMOR (Swiss). Ecole Polytechnique Federale de Lausanne (EPFL)
Modular Robotics: Topologies

- There are an infinite number of configurations that can be built
- A general classification is needed to study the properties of the subgroups
- We have proposed a classification based on the topology

**1D Topologies**: one chain of modules (Worms, snakes, arms, legs...)

**2D Topologies**: Two or more chains connected along different axes

**3D Topologies**: Three or more chains connected along different axes
Previous work:
Y1 Module

- **DOF**: 1
- **Material**: 3mm Plastic
- **Servo**: Futaba 3003
- **Dimension**: 52x52x72mm
- **Range**: 180 degrees
- Cheap and easy to build
- Two types of **connection**:
Previous work: Configurations

1D Topology:

Locomotion in 1D:
- Pitch-Pitch
- 8 pitch-connecting modules

Locomotion in 2D:
- Pitch-Yaw-Pitch
- 8 pitch-yaw-connecting modules

2D Topology:

Locomotion in 2D:
- Star of 3 modules
Overview of the robot: Mechanics

- 1D Topology
- 8 Pitch-yaw connecting modules
- 4 rotates around the pitch axes
- 4 rotates around the yaw axes
- Based on the Y1 modules
Overview of the robot: Control Hardware

- A small board based on the PIC16F876 (Skypic)
- Power supply and controller located off-board
- The locomotion algorithms are executed on a PC
- The PC is connected to the controller by RS-232
Control approach

- It is based on **Central Pattern Generators** (CPGs) to produce rhythmic motions.
- Our model of CPG is a generator of sinusoidal signals
- 4 CPGs controls the pitch modules and another 4 for the yaw ones.
- The **parameters** are:
  - Amplitude: $A_H, A_V$
  - Offset: $O_H, O_V$
  - Phase differences: $\Delta \phi_H, \Delta \phi_V, \Delta \phi_{VH}$
  - Period: $T$
Locomotion capabilities

- Using this control approach, 5 gaits have been achieved:
  - **1D sinusoidal gait**: Forward and backward movement
  - **Turning gait**: The robot moves along an arc
  - **Rolling gait**: The robot rolls around its body axis
  - **Rotating gait**: The robot rotates parallel to the ground
  - **Lateral shift**: The robot moves parallel to its body axis

- All these gaits have been simulated using the Open Dynamics Engine (ODE)
- They all have been implemented successfully on the robot
Locomotion capabilities:
1D sinusoidal gait

• Only the vertical joints are moving

• Parameters:

\[ A_V \neq 0 \]
\[ O_V = 0 \]
\[ A_H = 0 \]
\[ O_H = 0 \]
\[ \Delta \phi_V = 120 \]
Locomotion capabilities: Turning gait

- Only the vertical joints are moving
- Parameters:

\[
\begin{align*}
A_V &\neq 0 & A_H &= 0 \\
O_V &= 0 & O_H &\neq 0 \\
\Delta \phi_V &= 120
\end{align*}
\]
Locomotion capabilities: Rolling gait

- Parameters:

\[ A_V > 60 \quad A_H > 60 \]
\[ O_V = 0 \quad O_H = 0 \]
\[ \Delta \phi_V = 0 \quad \Delta \phi_H = 0 \quad \Delta \phi_{VH} = 90 \]
Locomotion capabilities: Rotating gait

- This is a **new gait** not previously mentioned by other researchers

- Parameters:

  \[
  A_V \neq 0 \quad A_H \neq 0 \\
  O_V = 0 \quad O_H = 0 \\
  \Delta \phi_V = 120 \quad \Delta \phi_H = 50 \\
  \Delta \phi_{VH} = 0
  \]
Locomotion capabilities: Lateral shift

• Parameters:

\[ A_V \neq 0 \quad A_H \neq 0 \]
\[ O_V = 0 \quad O_H = 0 \]
\[ \Delta \phi_V = 100 \]
\[ \Delta \phi_H = 100 \]
\[ \Delta \phi_{VH} = 0 \]
Let's see some videos...
Conclusions

- All the gaits have been implemented using a sinusoidal CPG approach.
- The parameters for achieving the gaits are summarized below:

<table>
<thead>
<tr>
<th>Sinusoidal</th>
<th>Turning</th>
<th>Lateral Shifting</th>
<th>Rotating</th>
<th>Rolling</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_v \neq 0$</td>
<td>$A_H = 0$</td>
<td>$O_v = 0$</td>
<td>$\Delta \Phi_V = 120$</td>
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<tr>
<td>$O_H = 0$</td>
<td>$O_H \neq 0$</td>
<td>$\Delta \Phi_V = 120$</td>
<td>$\Delta \Phi_V = 0$</td>
<td>$\Delta \Phi_V = 90$</td>
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<td>$\Delta \Phi_V = 100$</td>
<td>$\Delta \Phi_H = 50$</td>
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<td>$\Delta \Phi_V = 0$</td>
<td>$\Delta \Phi_V = 120$</td>
<td>$\Delta \Phi_H = 0$</td>
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<td>$\Delta \Phi_V = 0$</td>
<td>$\Delta \Phi_H = 0$</td>
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</tr>
</tbody>
</table>

- The experiments confirm the principles of CPGs and the locomotion capabilities of the pitch-yaw connecting modular robots.
Future work

- A new generation of modules have been designed:

- Now it is possible to build more complex configurations like a 4 legged or a humanoid robot:

- We are studying the climbing properties to develop a climbing caterpillar
Thank you very much for your attention
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