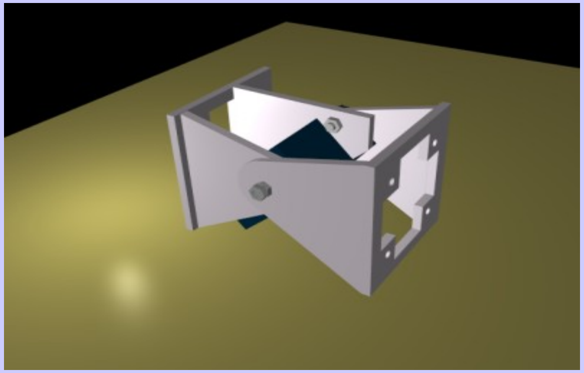
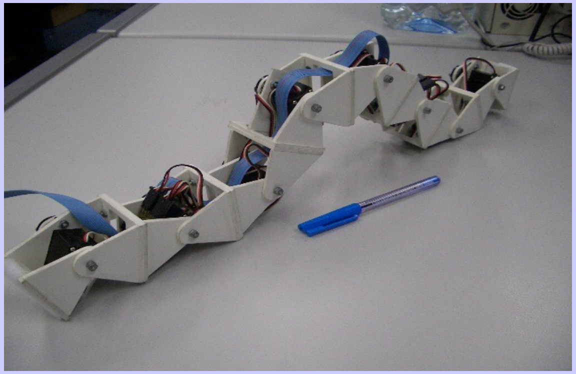
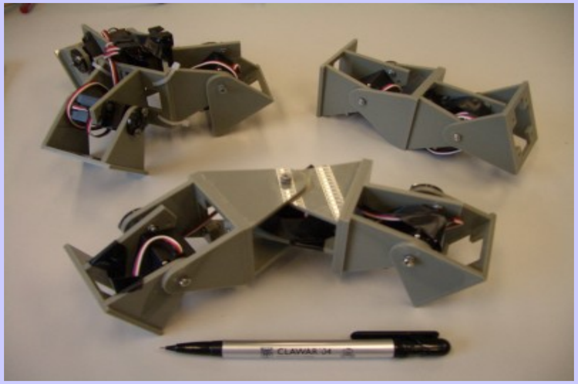
Modular robotics and locomotion







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- Introduction to Modular robotics
- Starting platform: Y1 Modules
- Locomotion of minimal configurations
- Locomotion of 1D worm-like robot
- Locomotion of 2D snake-like robots
- Future work

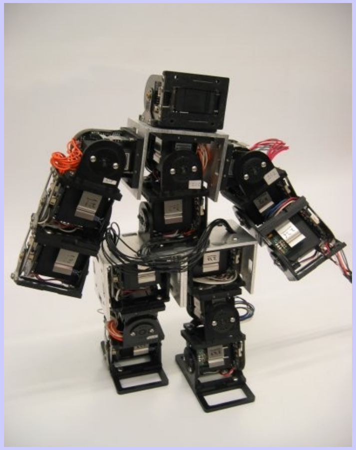
Introduction to Modular robotics

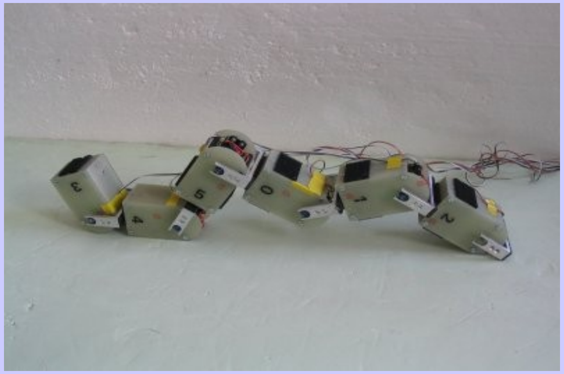
Introduction to Modular Robotics (I)

- 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**
- There are two kinds of modular robots:
  - **Manually reconfigurable robots**
  - **Self-reconfigurable robots**

Introduction to 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 avanced 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**)

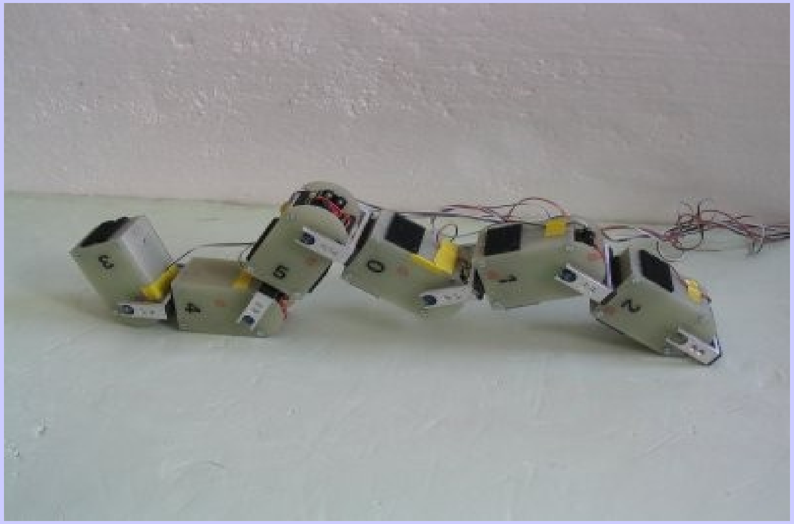


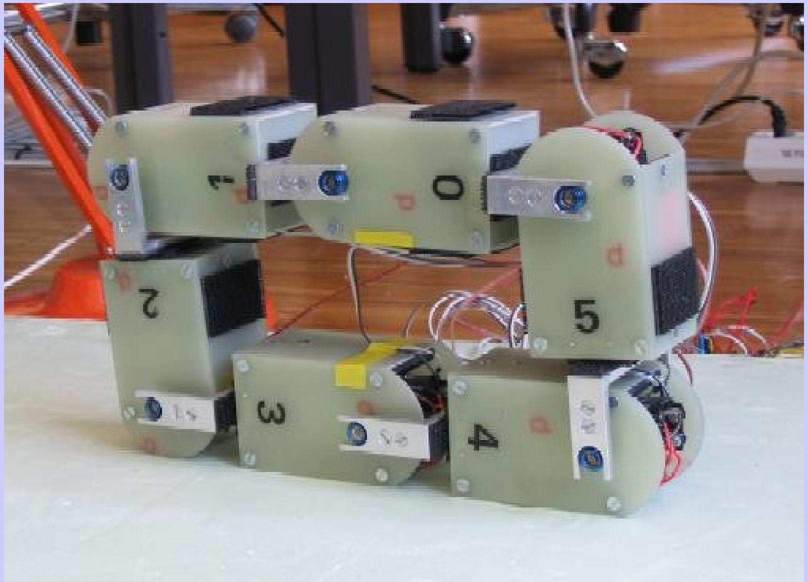


Introduction to Modular Robotics (V)

YAMOR

- The modules have 1 **DOF**
- Manually reconfigurable
- Control: ARM and FPGA
- Communication via bluetooth
- Connection using velcro





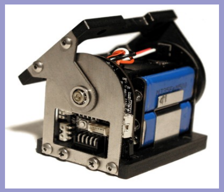
Introduction to Modular Robotics (III)

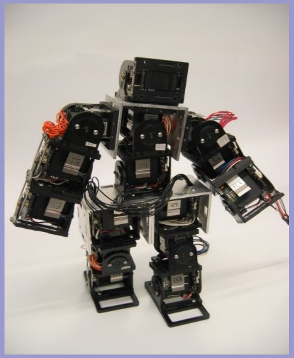
POLYBOT

- All the modules have 1 DOF
- 3 generations of modules

Generation 1

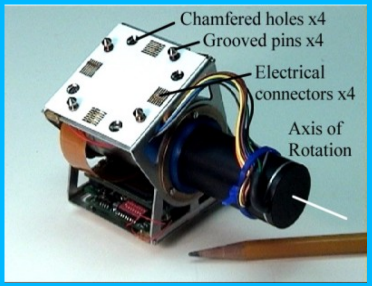
- Manually reconfigurable
- Many versions





Generation 2

- 11x7x6 cm
- Power PC 555
- 1MB Ram
- Can Bus
- Infrared emitters and detectors



Generation 3

- 5x5x5cm
- Maxon motor
- Similar electronics than G2

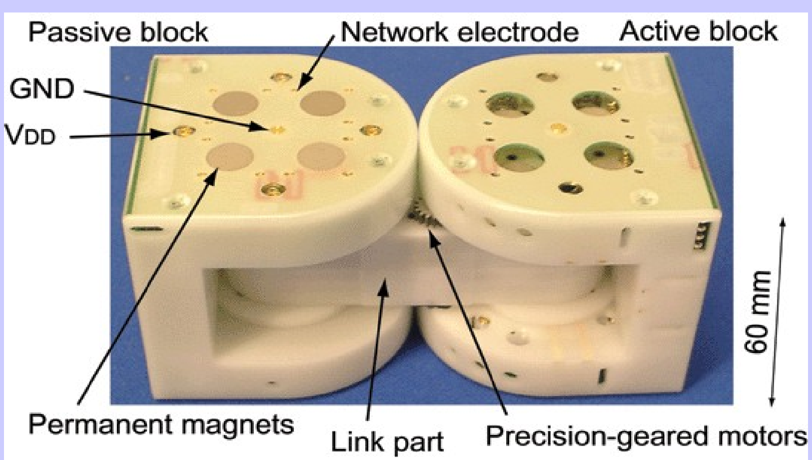
Introduction to Modular Robotics (IV)

M-TRAN

4 Legged

- All the modules have **2 DOF**
- 6x12x6 cm
- CPU: 1 Neuron Chip and 3 PICs
- Acceleration sensor

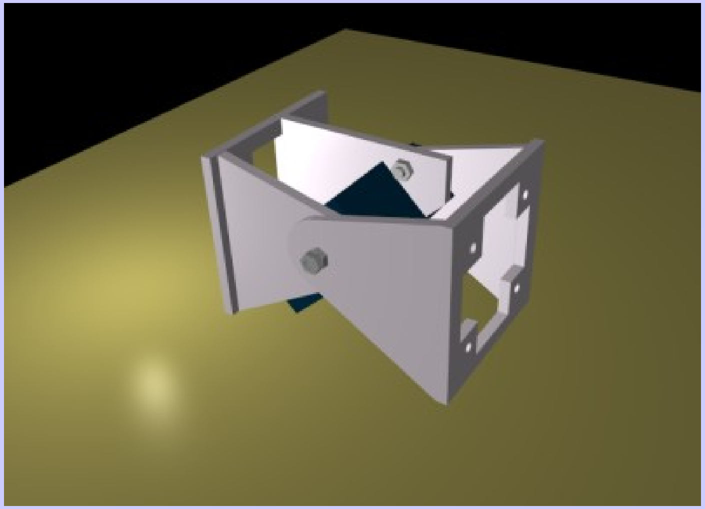
Wheel

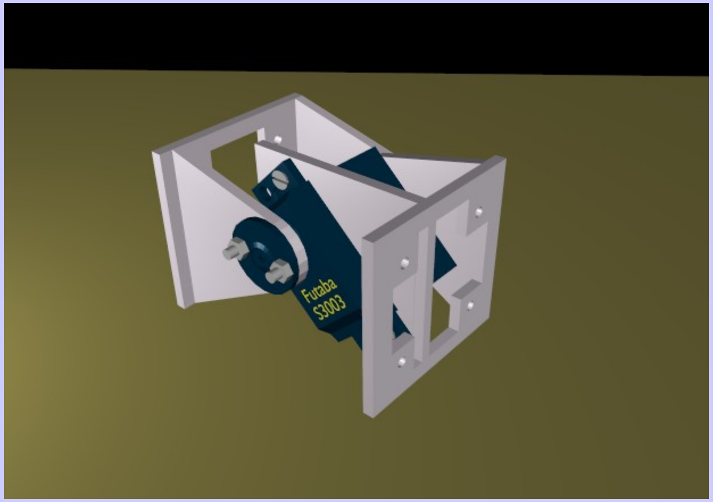


Snake

Video

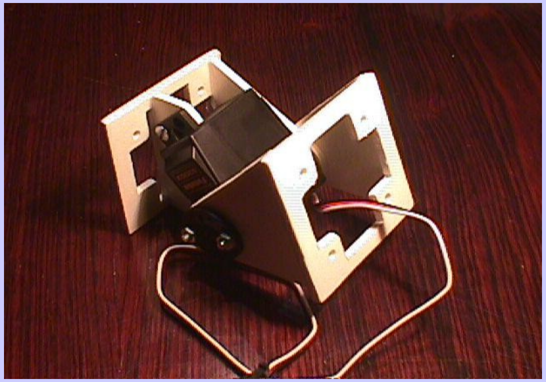
Starting platform:
Y1 Modules

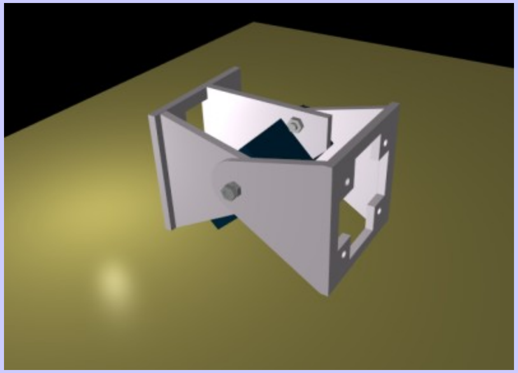




Y1 Modules: Introduction

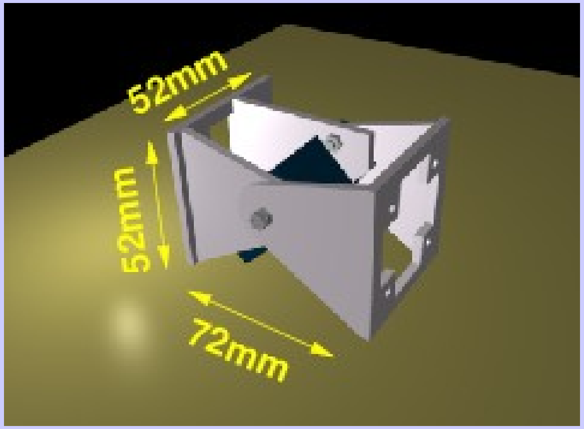
- We needed a cheap and easy-to-build platform to research on modular robotics
- It was not possible to buy the modules developed by the other groups
- **Y1 Modules** is the first generation
  - Fast prototyping
  - Manually reconfigurable robots
  - Students can build them very easily



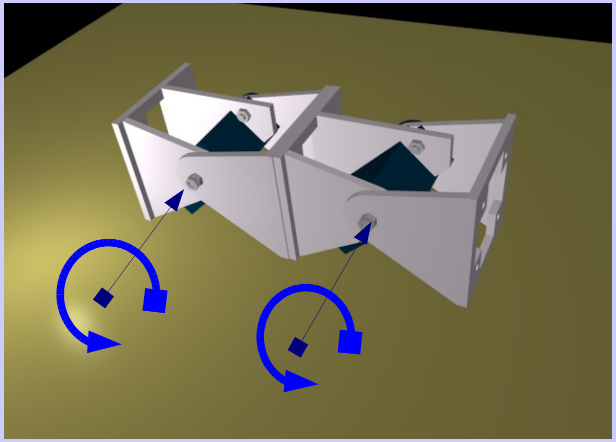


Y1 module: Characteristics

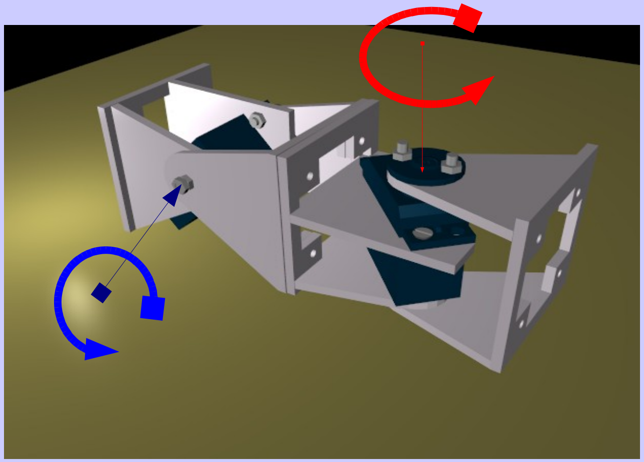
- **Material**: 3mm Plastic
- **Servo:** Futaba 3003
- **Dimension**: 52x52x72mm
- **Range**: 180 degrees
- Two types of connection:



Same orientation

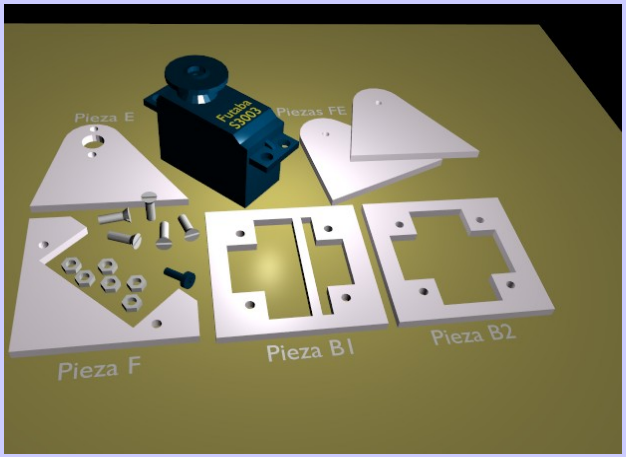


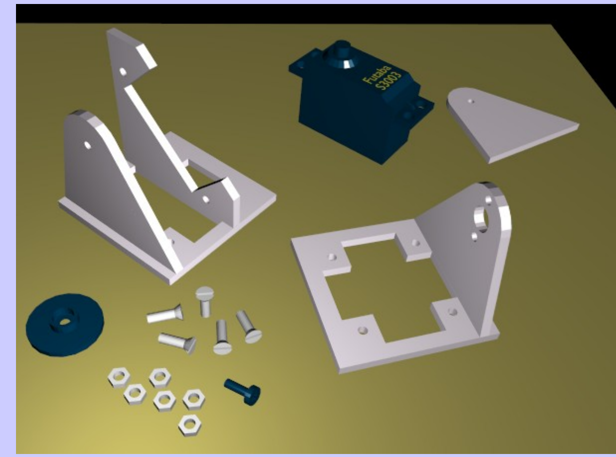
90 degrees rotation

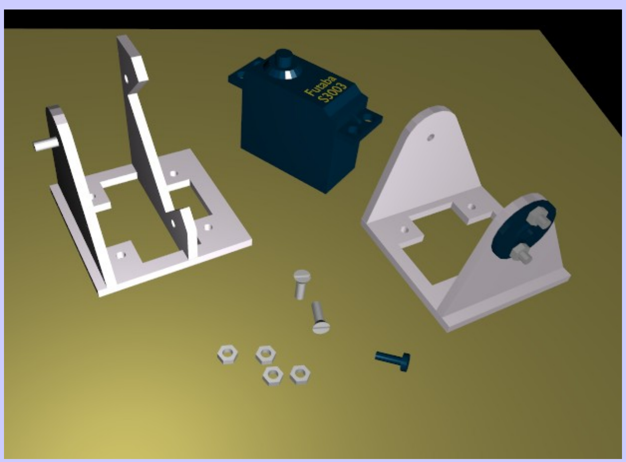


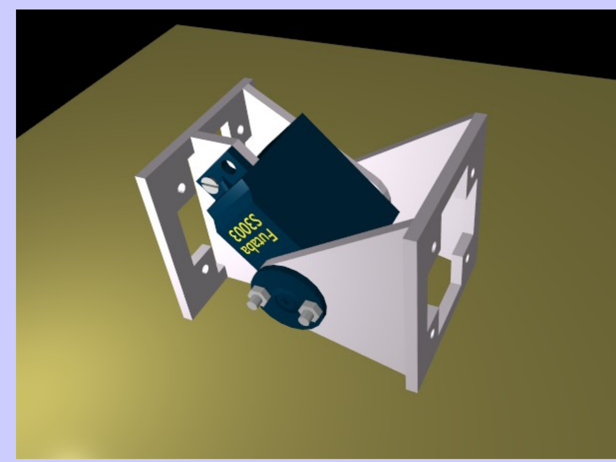
Video

Y1 modules:
Building in 6 steps



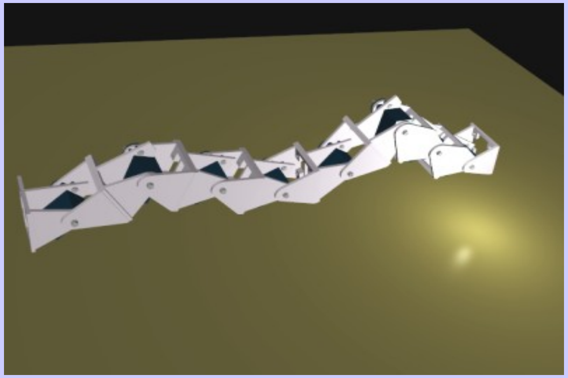


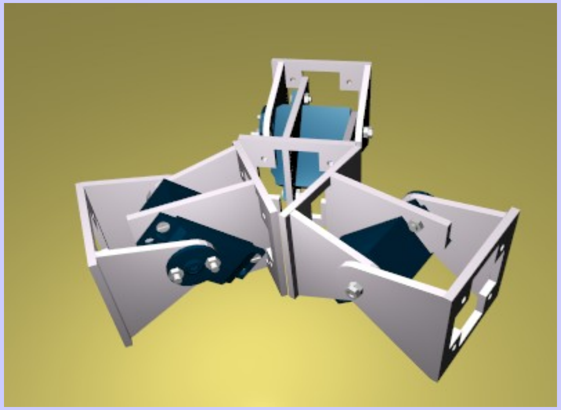




Y1 modules: Topology

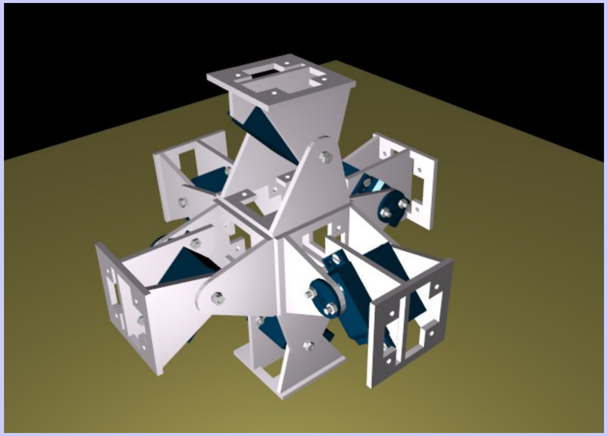
1D: Chain robots
(Worms, snakes)





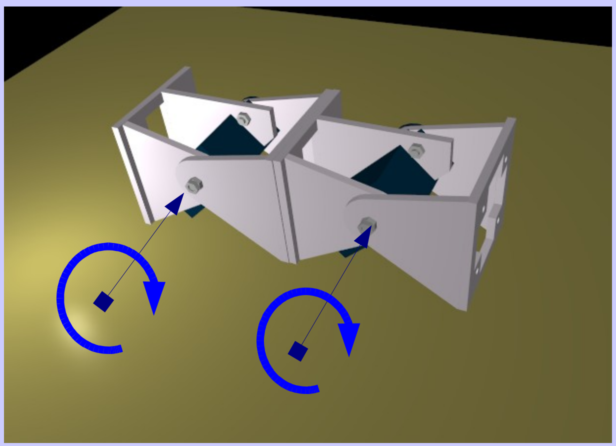
2D structures

3D structures

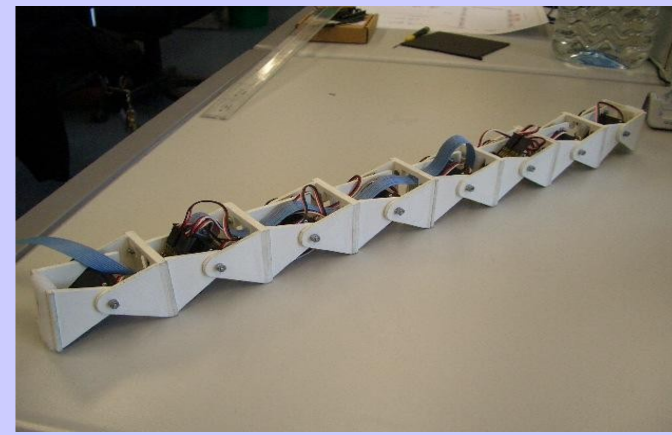


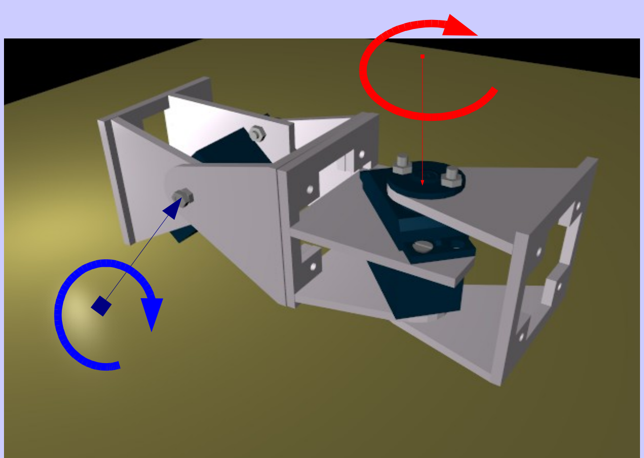
Y1 Modules:
1D Topology (Chain robots)

- Two different type of robots:

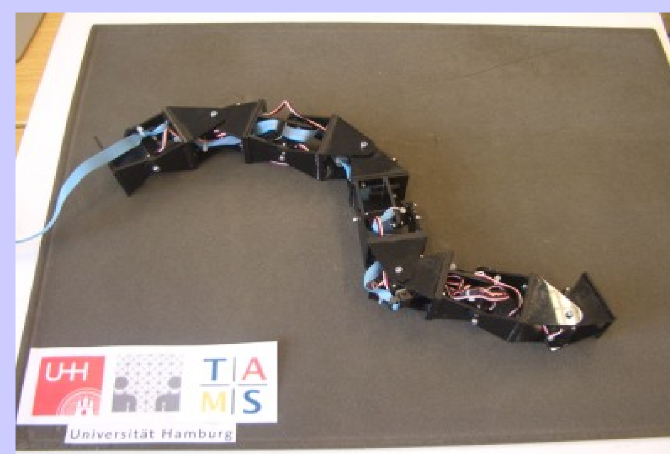


Same orientation →



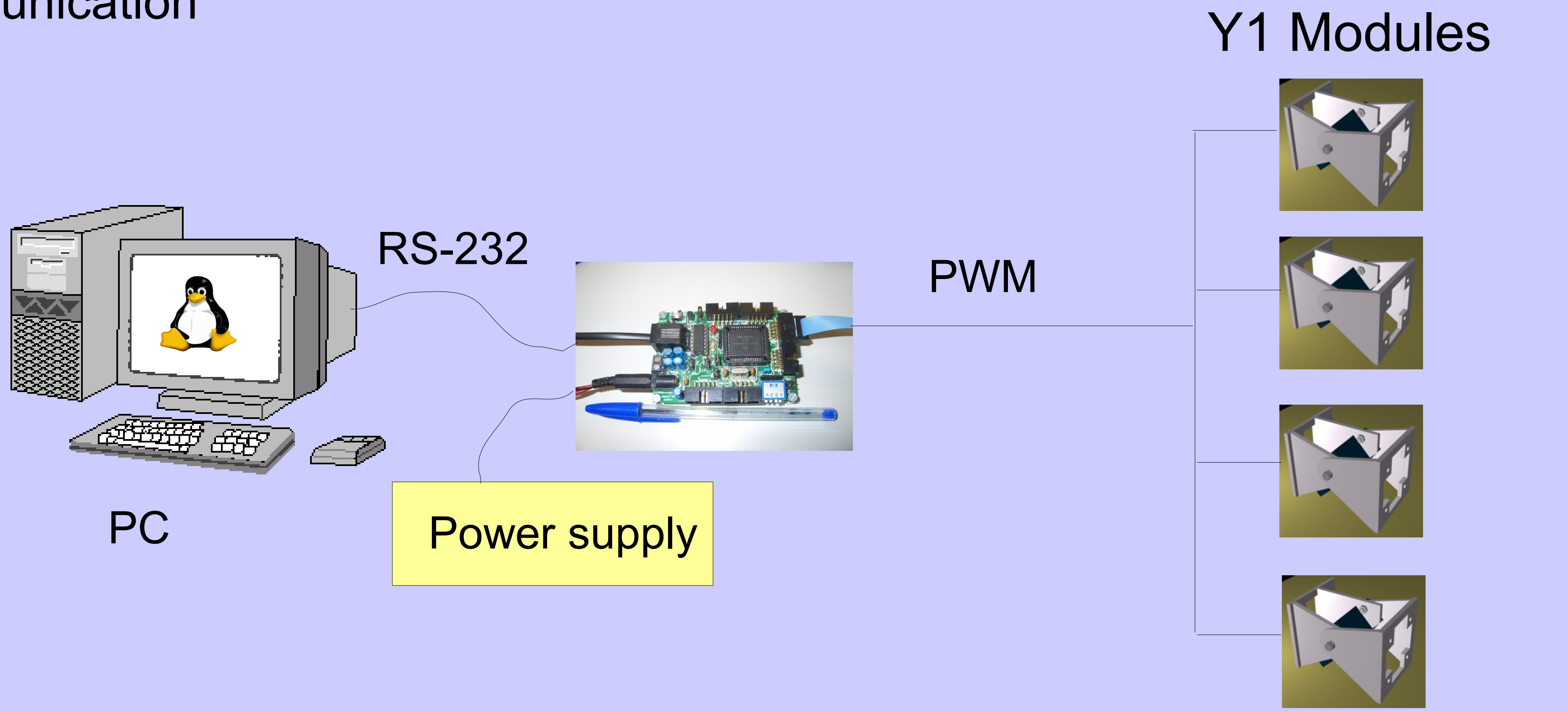


90 degrees rotation →

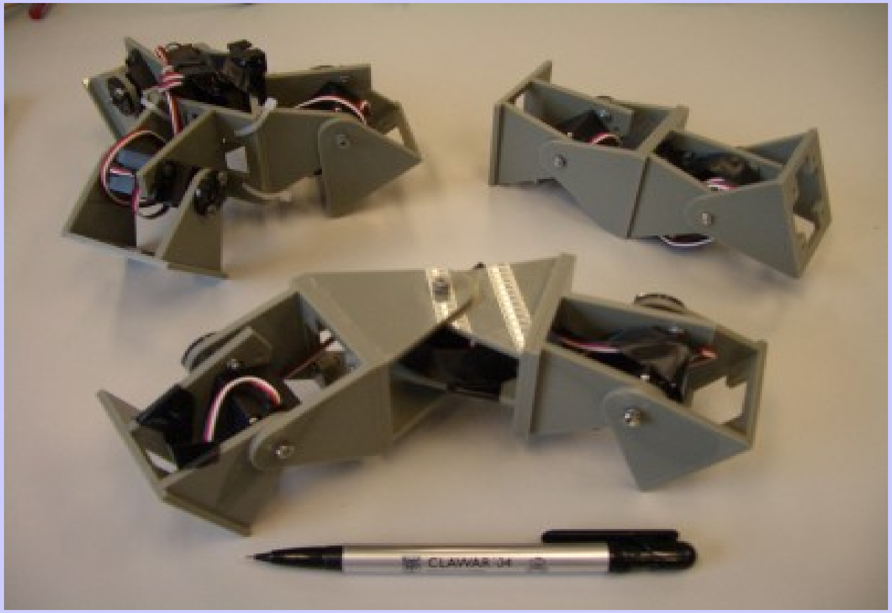


Y1 modules: Electronics

- The electronic and power supply are located outside the module
- An 8 bits microcontroller is used for the generation of the PWM signal that position the servos
- The software running in the PC send the position to the servos by serial communication



Locomotion of minimal configurations



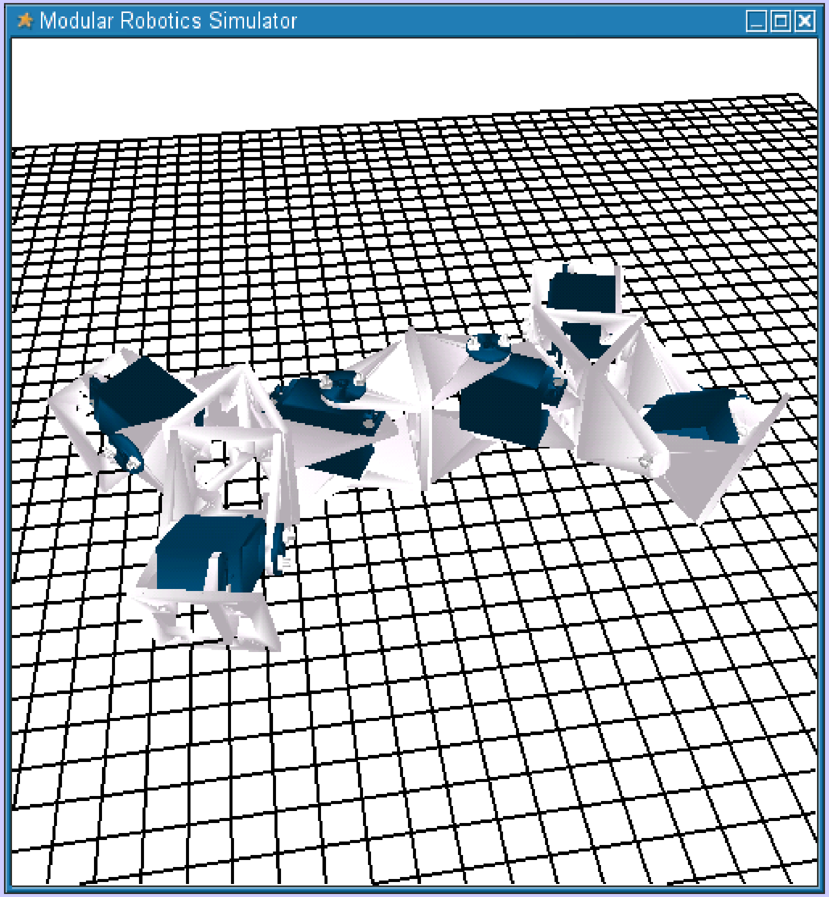
Introduction

• Complex robots can be constructed by attaching these modules

• But, what we wonder is:

What is the minimum number of modules needed to achieve locomotion in 1D and 2D?

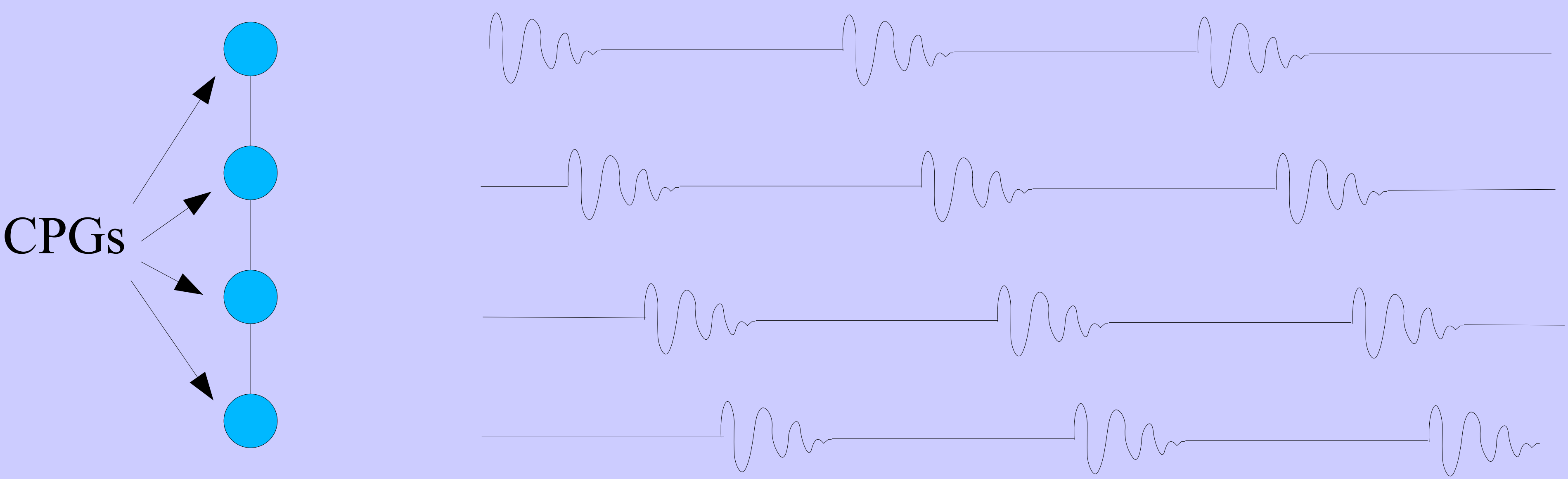
How do these modules have to be coordinated to achieve the locomotion?



• In order to answer these questions, we have constructed three prototypes

Locomotion using CPGs

- There are **two main approaches** for implementing the locomotion of an articulated robot
  - The classic way is based on **inverse kinematics** and the position of the **centre of gravity**
  - There is a new bio-inspired approach, based on the central patter generator (**CPG**) of the vertebrates
- CPG are oscillators that generate periodic signals



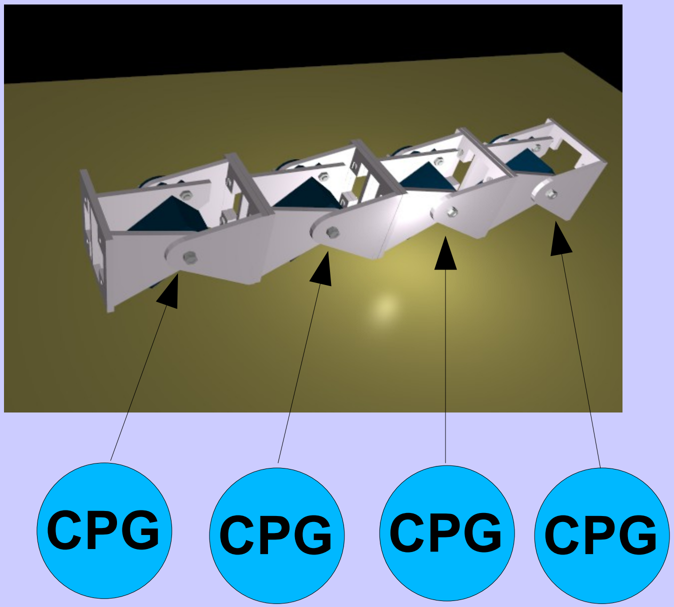
Locomotion using CPGs (II)

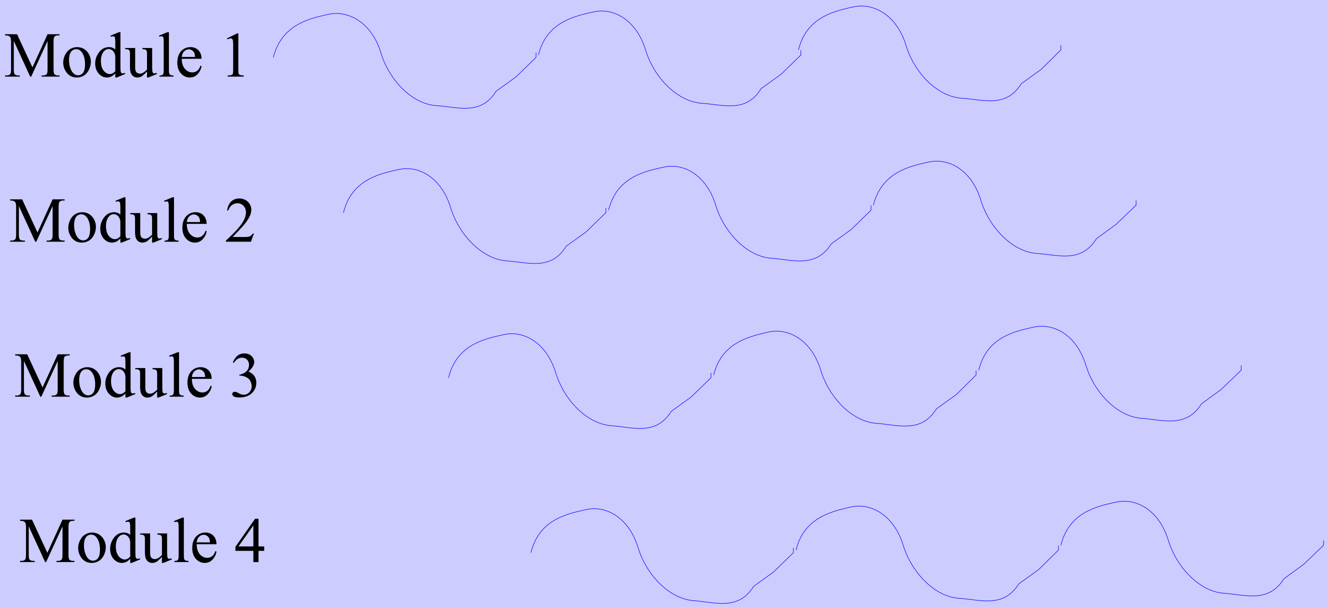
- We use a simplified CPG model, based on a sine function

CPG

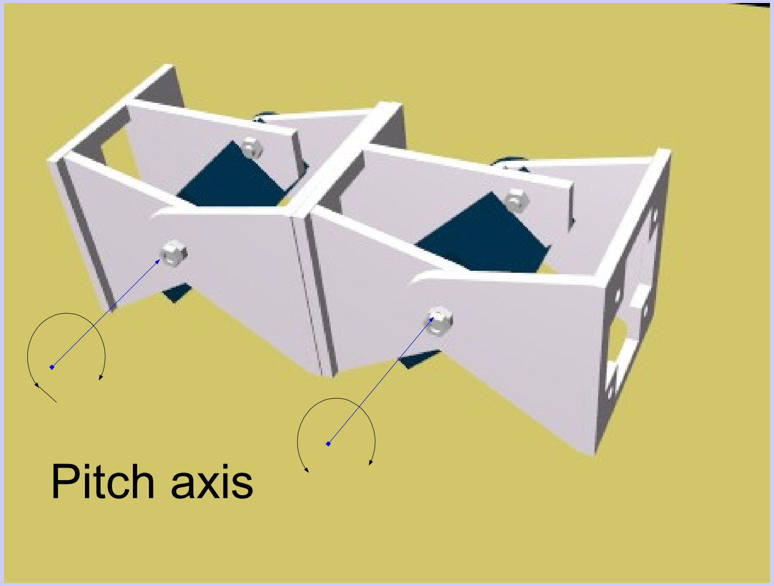
$$\varphi = A\sin\left(\frac{2\pi}{T}t+\phi\right)$$

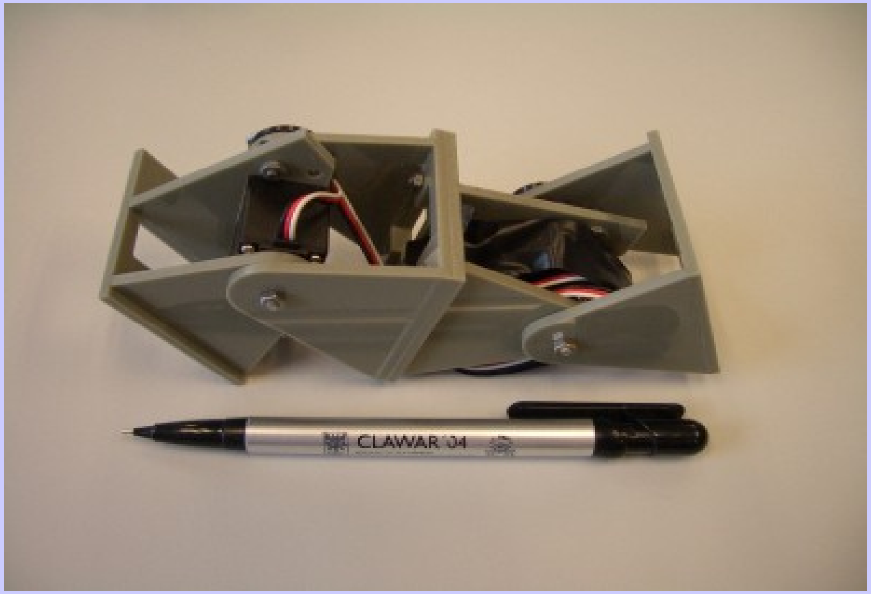
- There are one CPG per module:





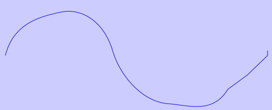
Configuration I (Pitch-Pitch) Description



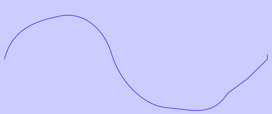


- We call it Pitch-Pitch configuration (PP)
- Two modules connected in the same orientation
- They both move about the pitch axis
- 1D sinusoidal gait

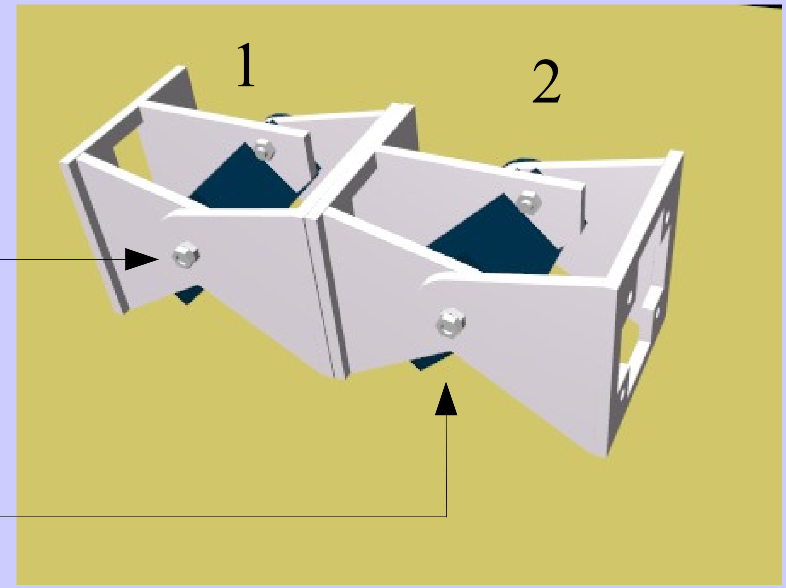
Configuration I (Pitch-Pitch) Coordination



$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$

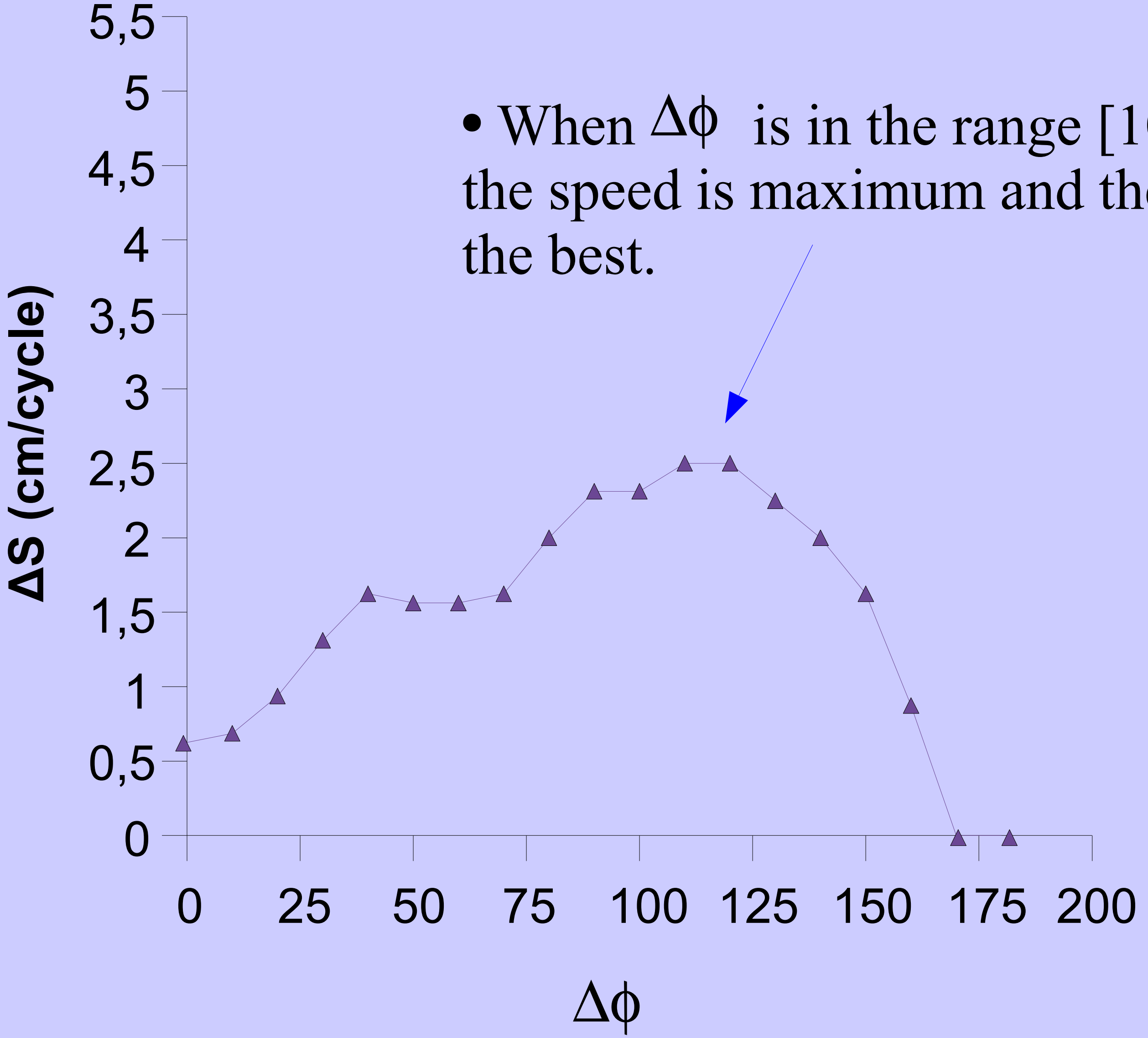


$$\varphi_2 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi\right)$$



- Two sinusoidal waves are applied to each articulation
- These waves only differ on the phase ($\Delta\phi$)
- $\Delta\phi$ determines the coordination of the movement

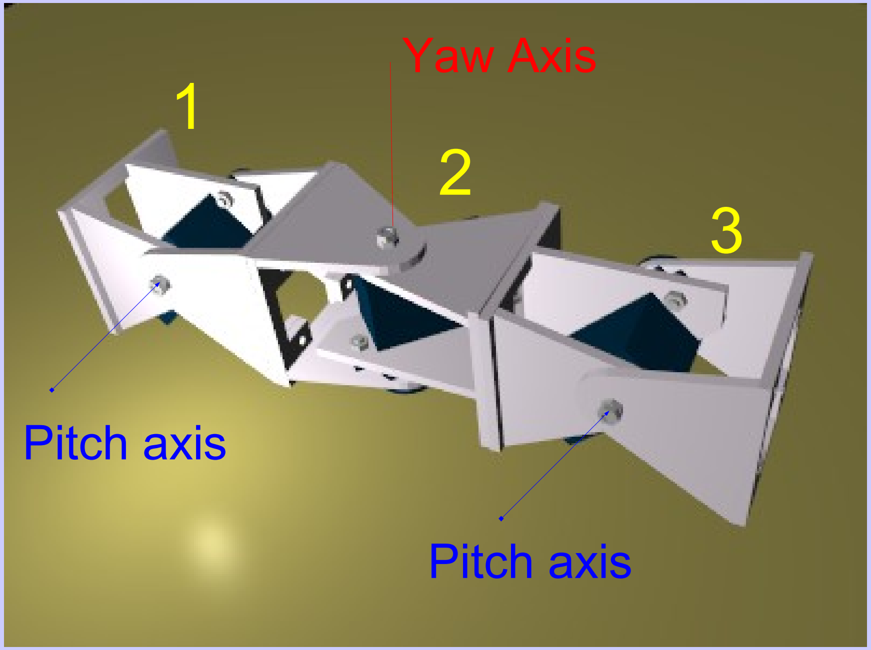
Configuration I (Pitch-Pitch)
Results

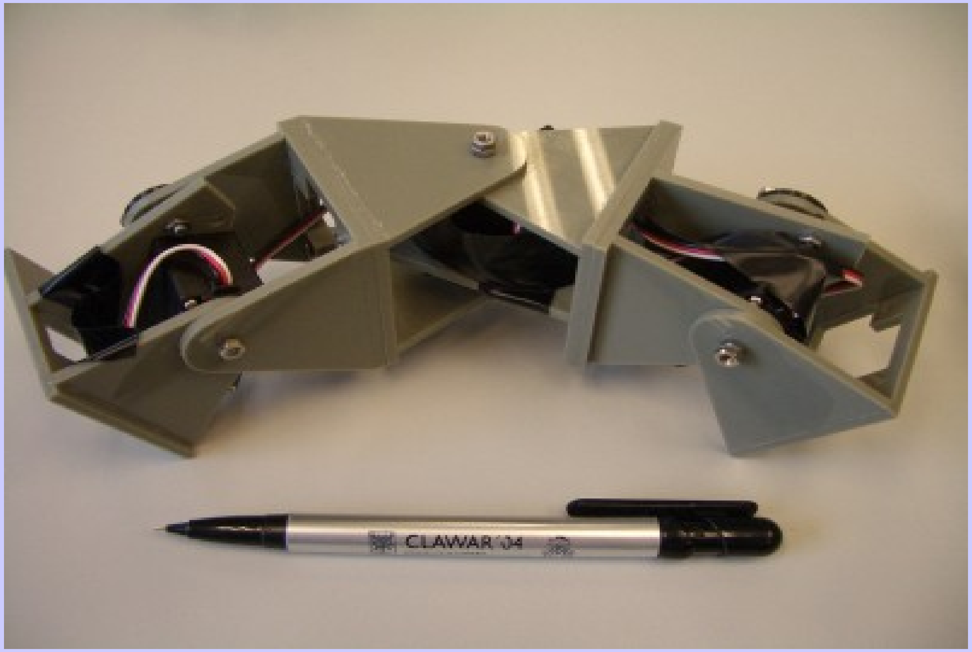


- When $\Delta\phi$ is in the range [100, 130] degrees, the speed is maximum and the coordination is the best.

Video

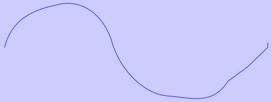
Configuration II (Pitch-Yaw-Pitch) Description





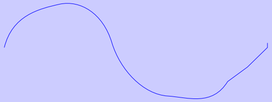
- Three modules: two rotating in the pitch axis and one in the yaw
- We call it Pitch-Yaw-Pitch configuration (PYP)
- 1D and 2D sinusoidal gait
- Lateral shift gait
- Lateral rolling gait

Configuration II (Pitch-Yaw-Pitch)
1D sinusoidal gait

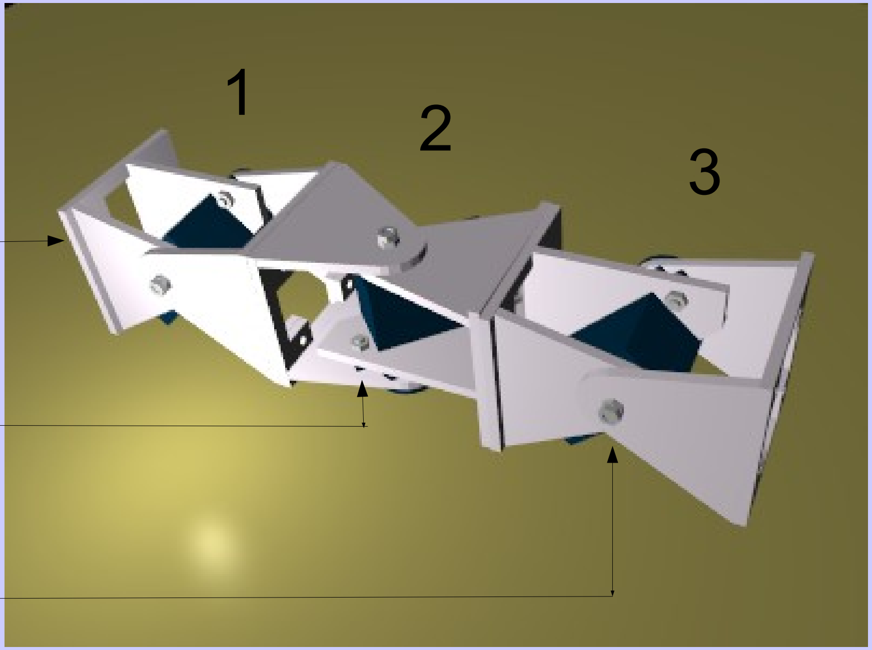


$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$

$$\varphi_2 = 0$$

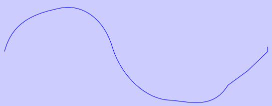


$$\varphi_3 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi\right)$$



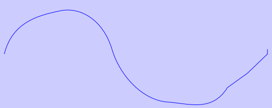
- The angle of articulation 2 fixed to 0 degrees
- Articulations 1 and 3 coordinated in the same way that in the PP configuration
- Sames results as in configuration PP

Configuration II (Pitch-Yaw-Pitch)
2D sinusoidal gait

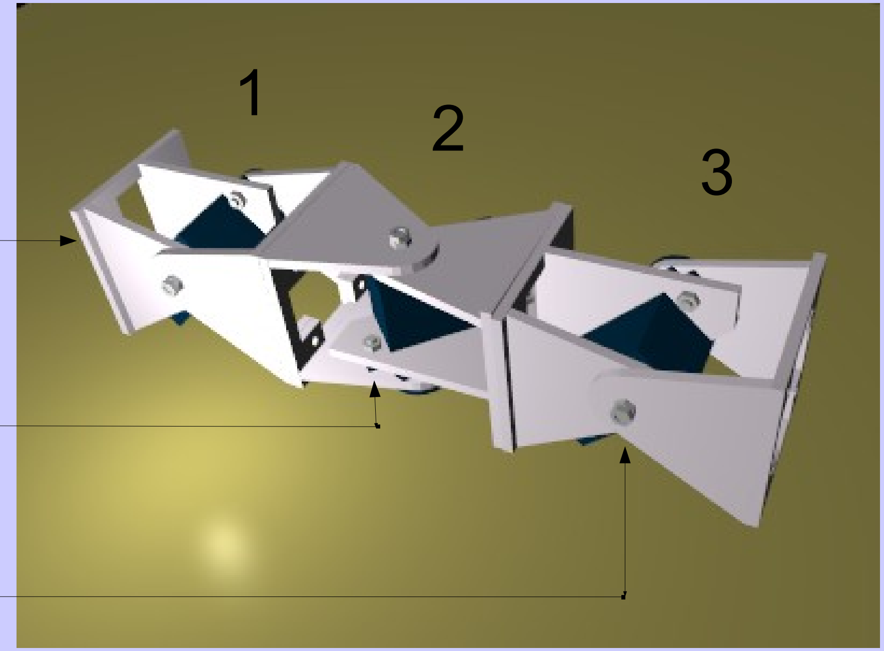


$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$

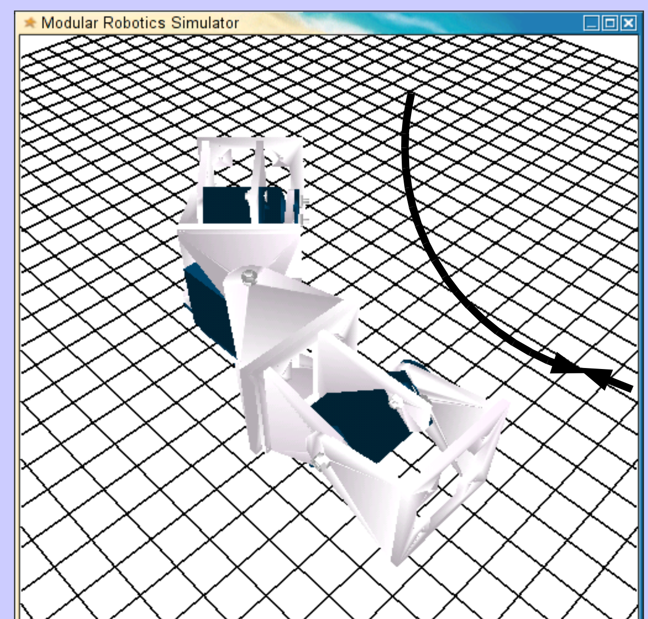
$$\varphi_2 \neq 0$$



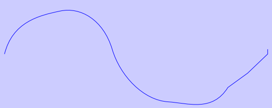
$$\varphi_3 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi\right)$$



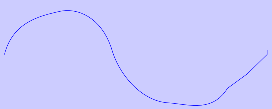
- The same as in 1D sinusoidal gait, but the angle of articulation 2 different from 0 degrees
- The trajectory of the robot is an arc



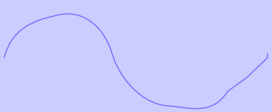
Configuration II (Pitch-Yaw-Pitch)
Lateral shift gait



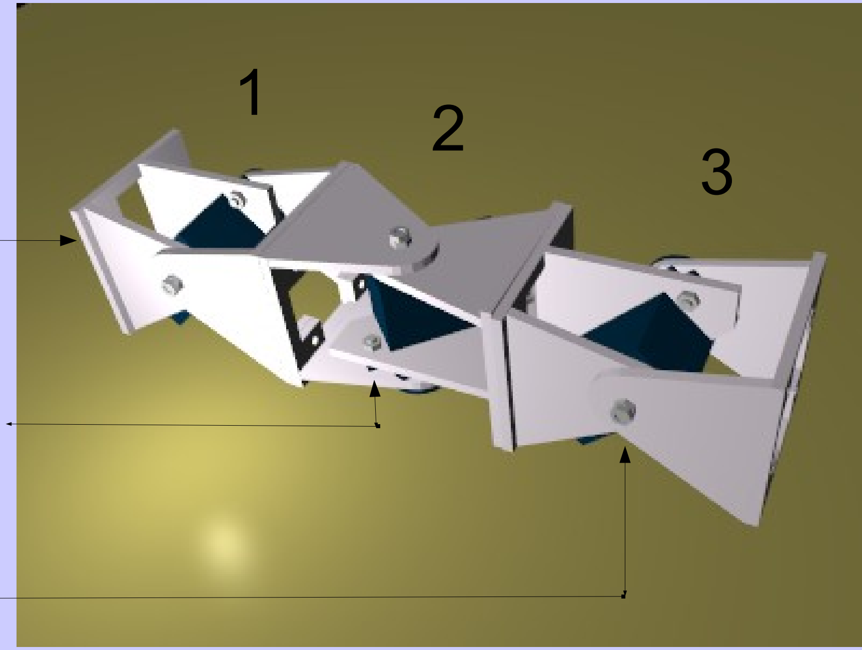
$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$



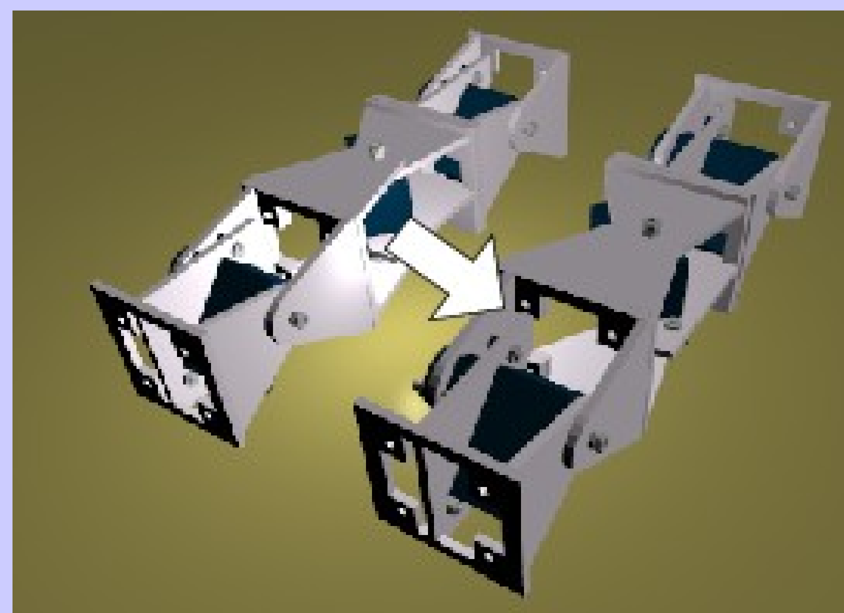
$$\varphi_2 = A\sin\left(\frac{2\pi}{T}t + \frac{\pi}{2}\right)$$



$$\varphi_3 = \varphi_1$$



- **A<=40**
- Module 1 and 3 are in phase
- Module 2 is 90 degrees out of phase
- The robot moves parallel to its body axis

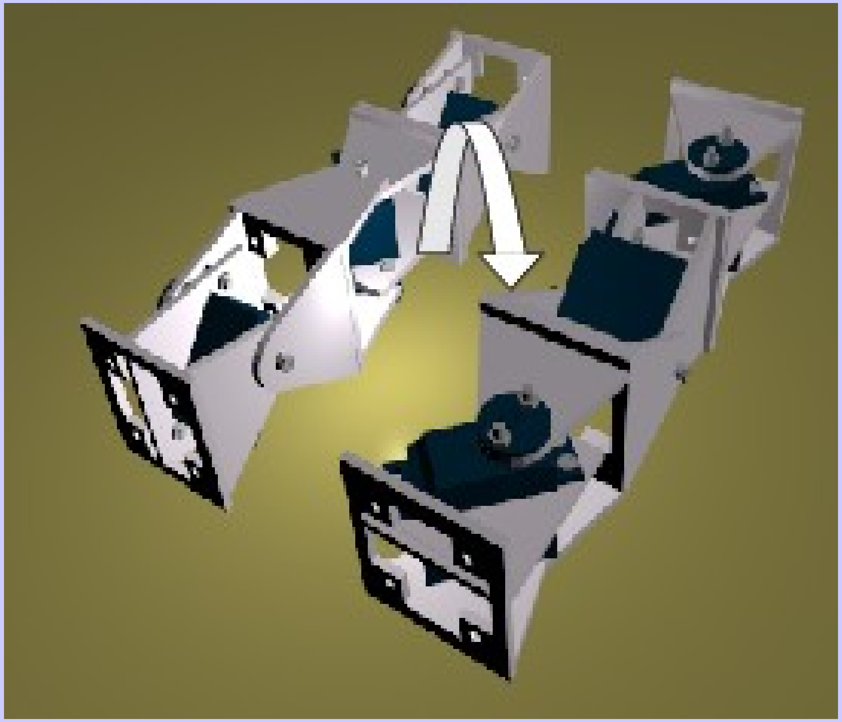


Configuration II (Pitch-Yaw-Pitch)
Lateral rolling gait

- The same coordination as in the lateral shift gait, but using amplitude **A>60** degrees.

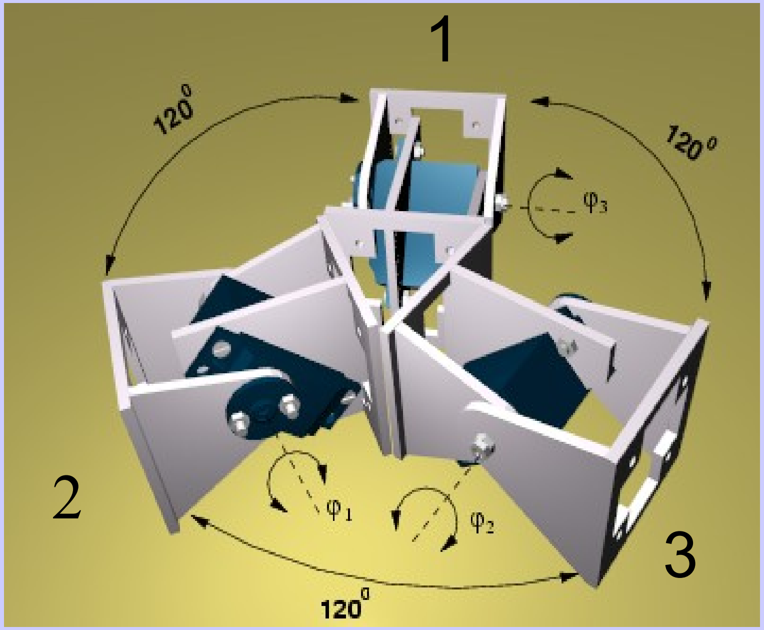
- The sense of rolling can also be controlled by changing the sign of the difference of phase

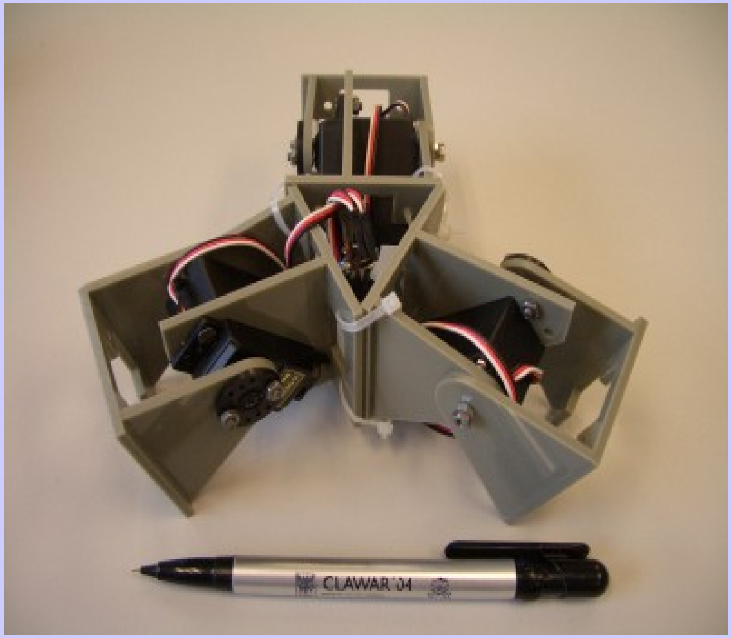
- The robot rolls about its body axis



Video

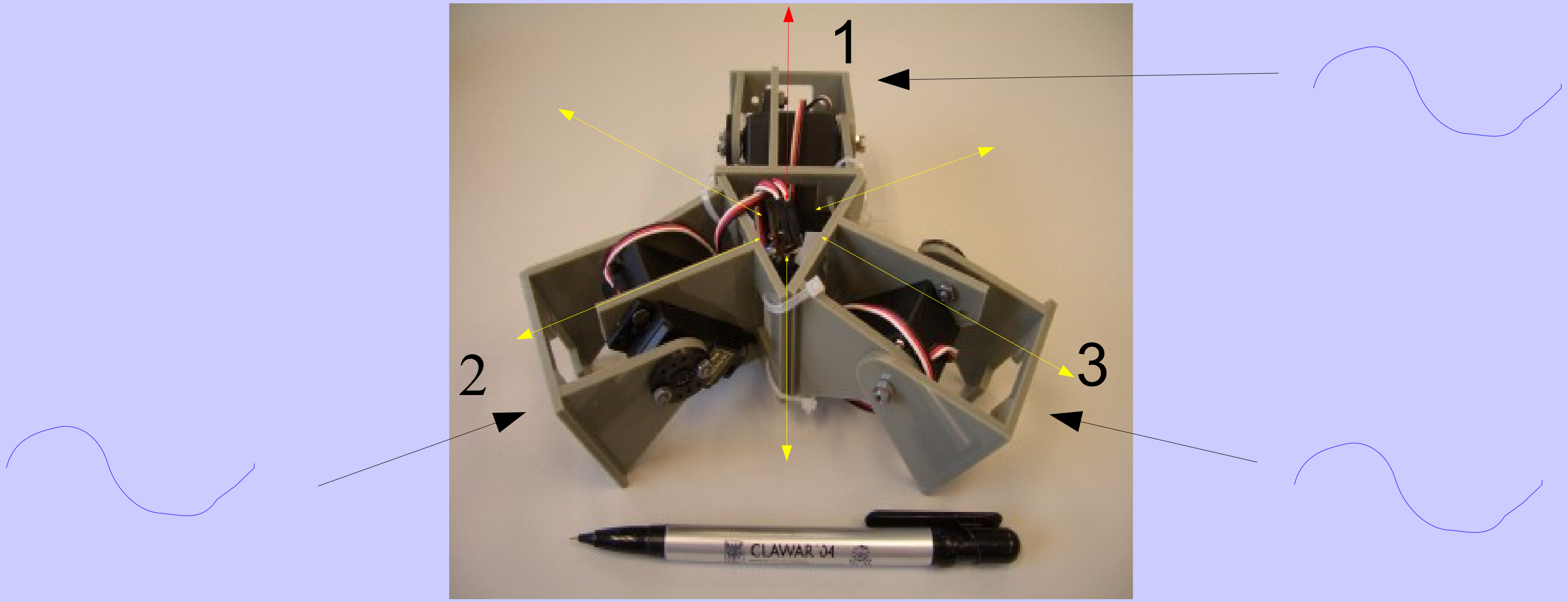
Configuration III: three-modules star
Description





- Three modules in the same plane, moving about its pitch axis
- The angle between the modules is 120 degrees (connected in a three-points-star form)
- 1D sinusoidal gait along six different directions
- Rotation about the robot's yaw axis

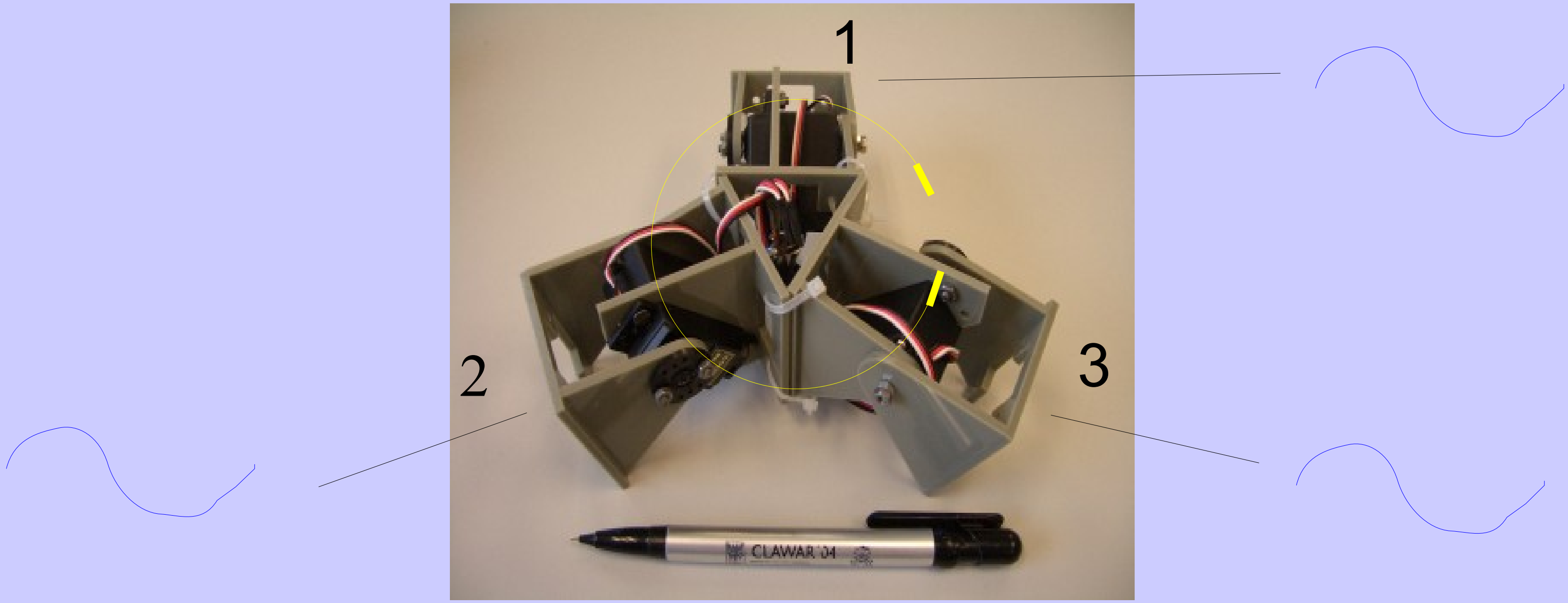
Configuration III: three-modules star
1D sinusoidal gait



- The robot can move along six different directions
- Three sinusoidal waves are applied
- Example: In order to move along the red direction:

$$\varphi_2 = \varphi_3 = A\sin\left(\frac{2\pi}{T}\right) \qquad \varphi_1 = A\sin\left(\frac{2\pi}{T} + \Delta\phi\right) \qquad 100 < \Delta\phi < 130$$

Configuration III: three-modules star Rotation about its yaw axis

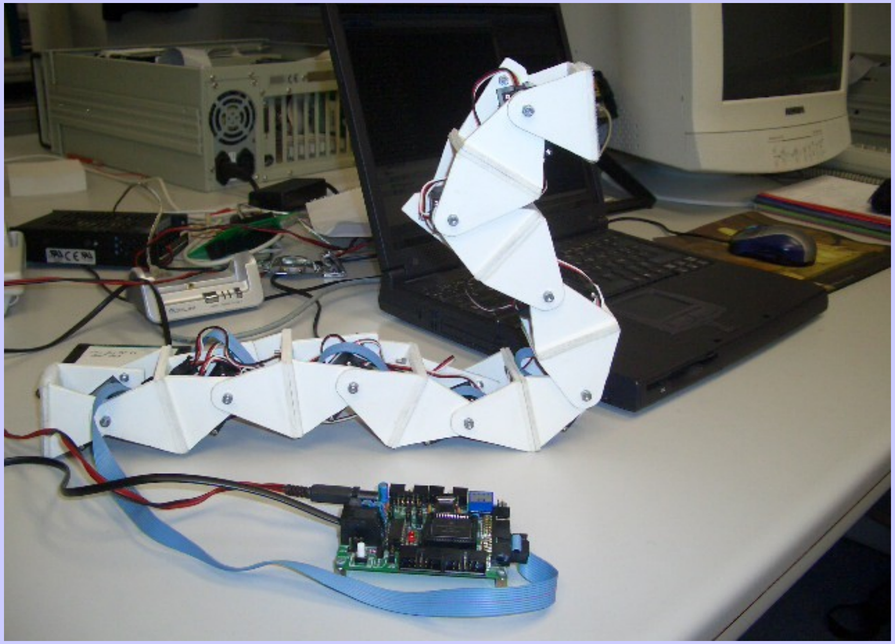


- Rotation about the robot yaw axis
- Three sinusoidal waves are applied

$$\varphi_1 = A\sin\left(\frac{2\pi}{T}\right) \qquad \varphi_2 = A\sin\left(\frac{2\pi}{T} + \frac{2\pi}{3}\right) \qquad \varphi_3 = A\sin\left(\frac{2\pi}{T} + \frac{4\pi}{3}\right)$$

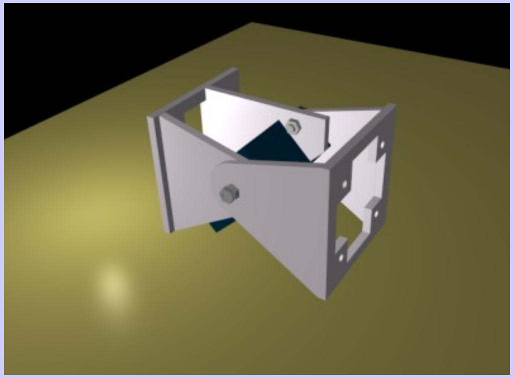
Video

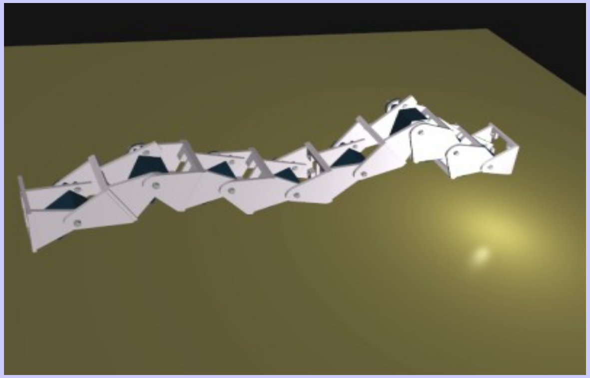
Locomotion of 1D worm-like robot



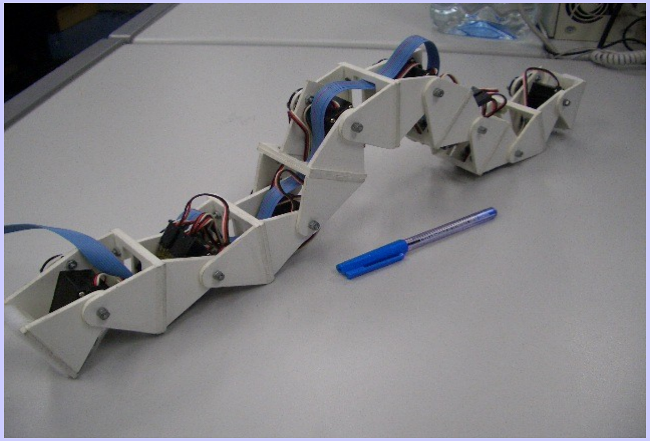
1D chain robot: Introduction

- **Configuration**: 8 Y1 modules in the same orientation



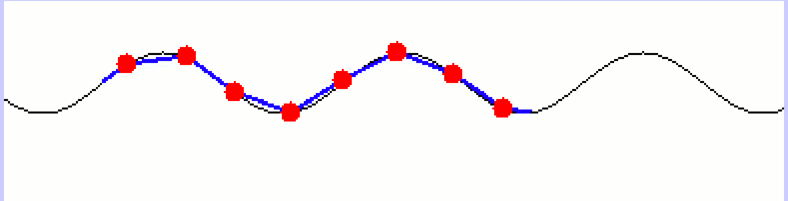


- **Dimensions:** 52x52x576mm:



1D Chain robot: Locomotion approaches

- Two approaches can be used for the locomotion:
  - Using 8 CPGs
  - Using a global wave that travel through the robot, from the tail to the head

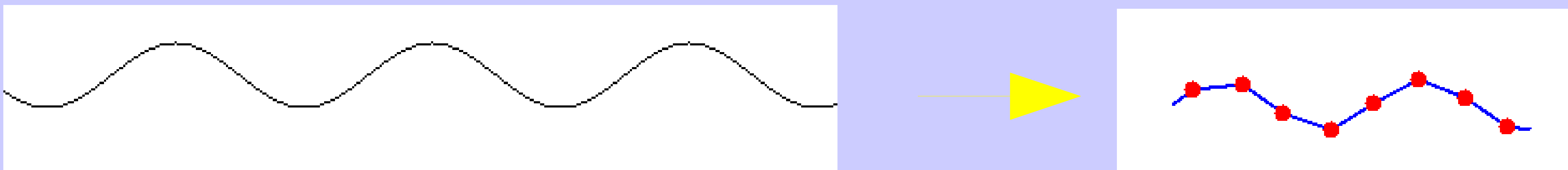


- For the second approach only 4 parameters have to be specified:
  - Waveform
  - Wavelength
  - Amplitude
  - Period

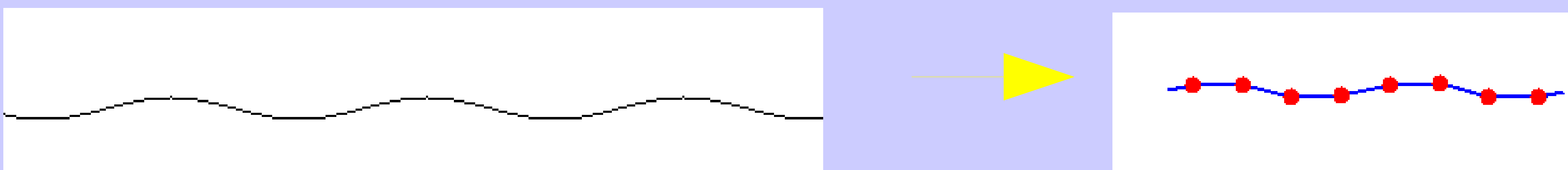
1D chain robots: Global waves

- The locomotion characteristics depend on the global wave used:

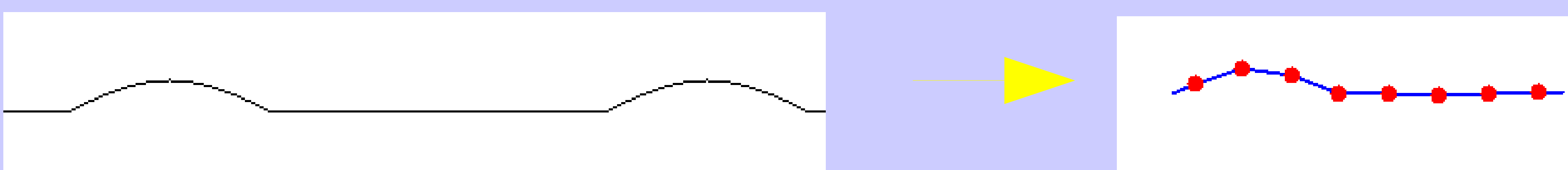
High amplitude: Crossing over obstacles



Low amplitude: Going inside a tube

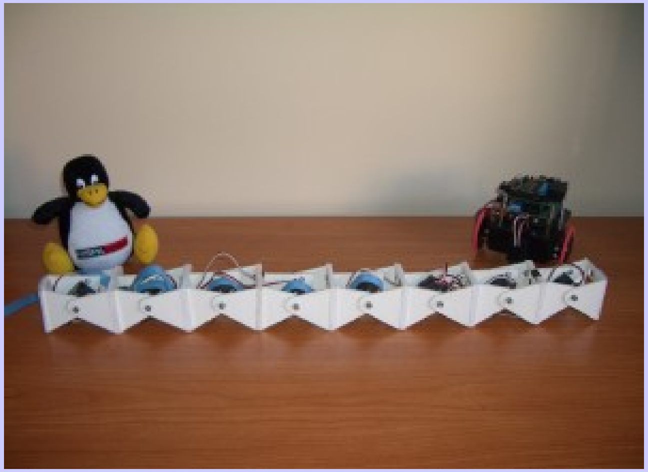


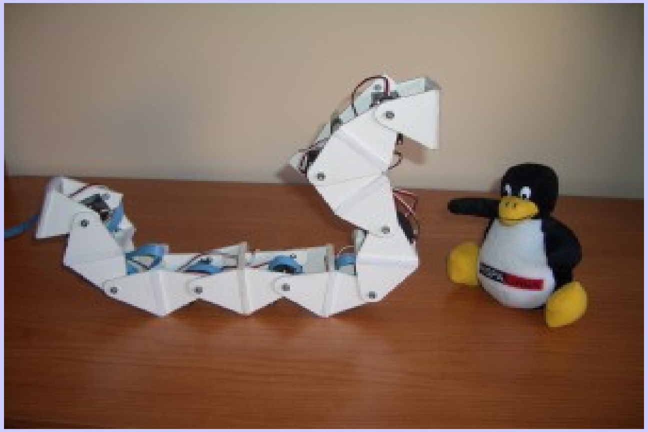
Semi-sine wave: Caterpillar locomotion

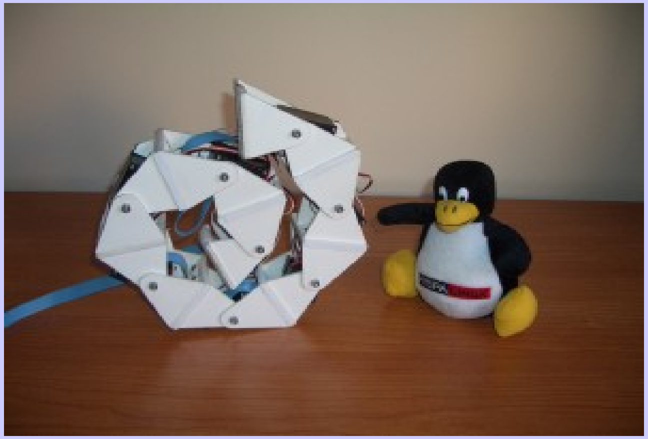


1D chain robots:
Locomotion capabilities

- One feature of these robots is that they can change their shape:





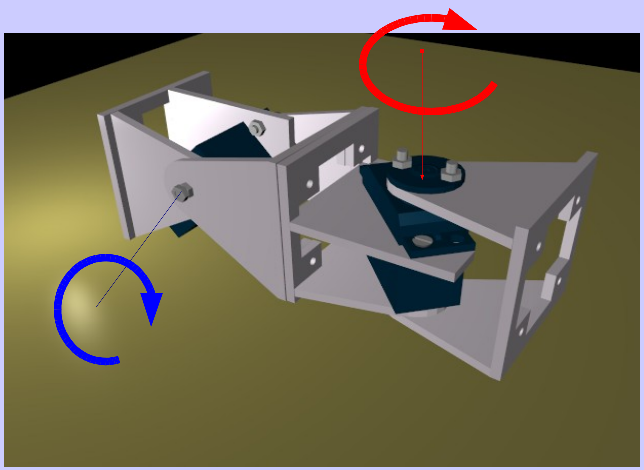


Video

Locomotion of 2D chain robot

Chain robot 2D: Introduction

- Robot composed of 8 Y1 modules
- Two adjacent modules are 90 degrees rotated

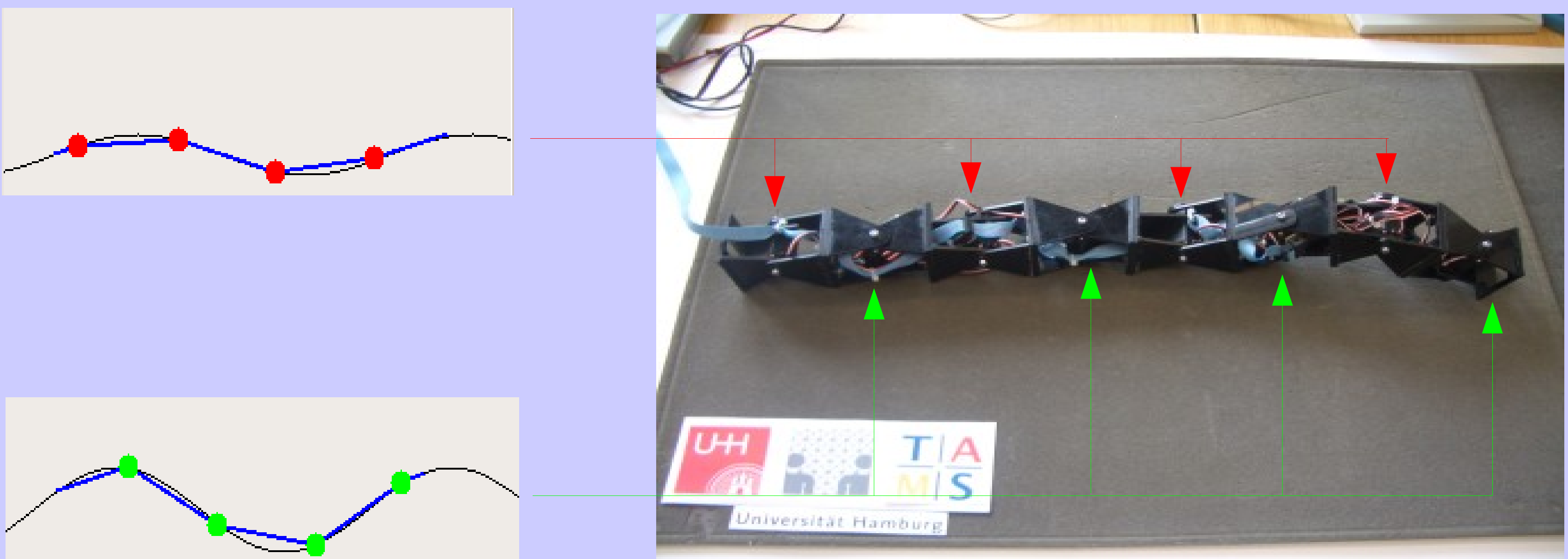


90 degrees rotation

- This robot have the following locomotion capabilities:
  - 1D locomotion
  - 1D locomotion in an arc
  - Lateral shift
  - Rotating parallel to the ground
  - Lateral rolling

Chain robot 2D: Control approaches

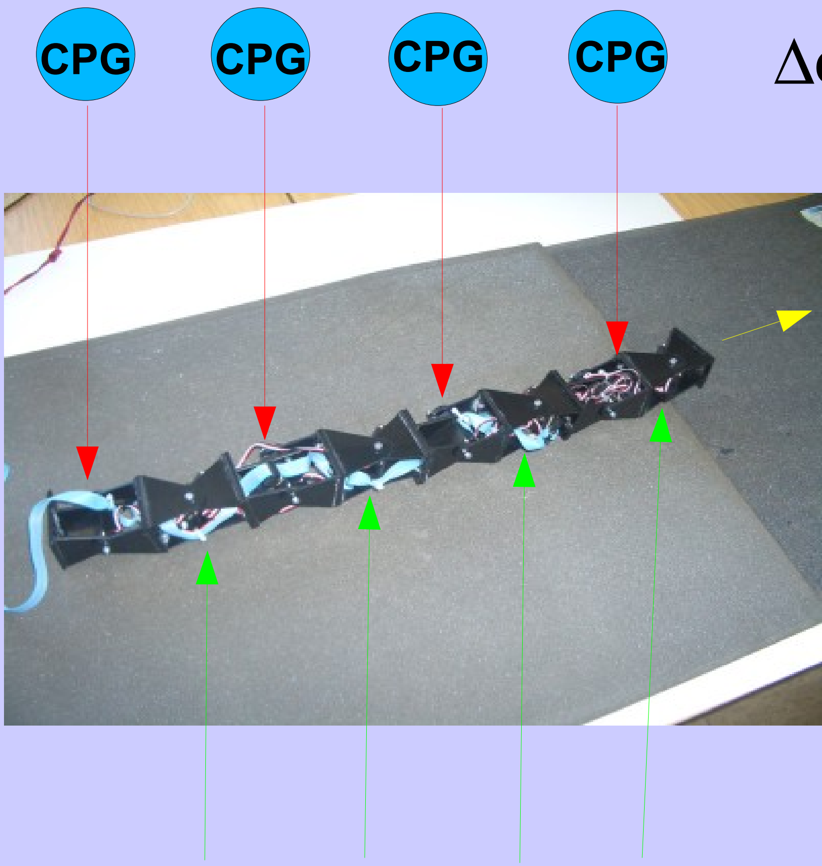
- Using 8 CPGs
- Using two global waves. One for the vertical modules and the other for the horizontal:



- Some gaits are easier to implement with the first approach and others with the second

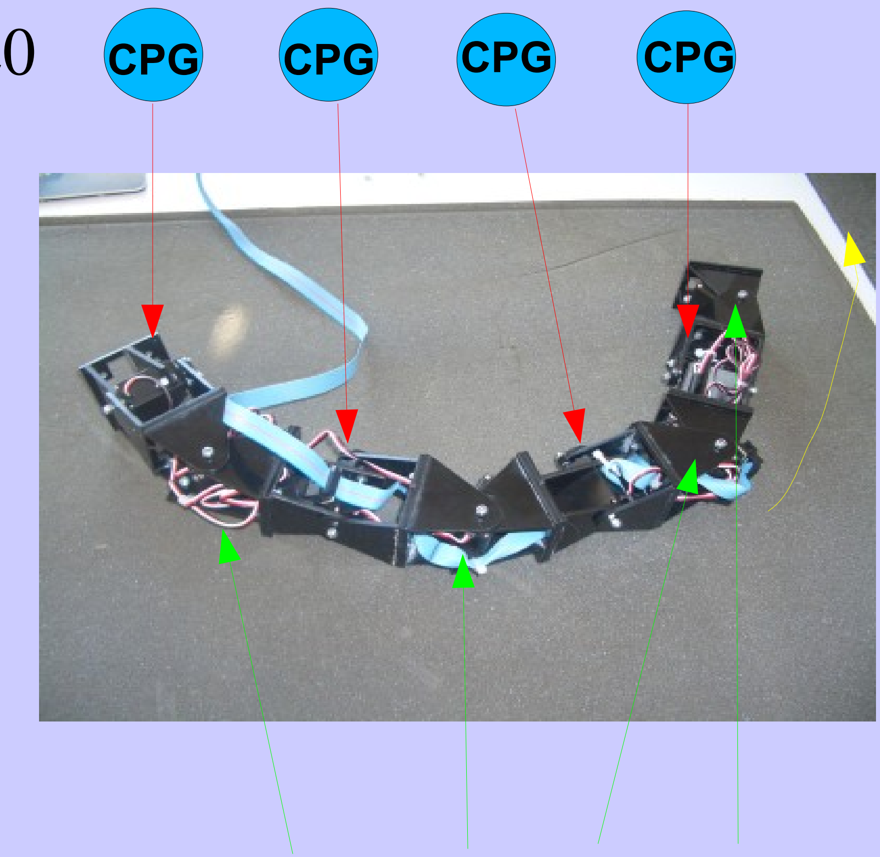
Chain robot 2D:
1D locomotion

- **Locomotion in 1D**: straight and arc trajectories



Fixed: 0 degrees

$\Delta\phi=120$

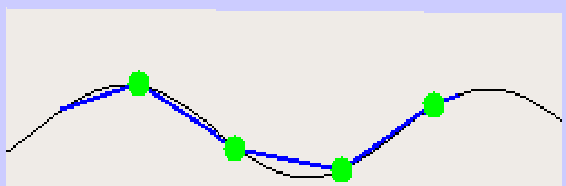


Fixed: 30 degrees

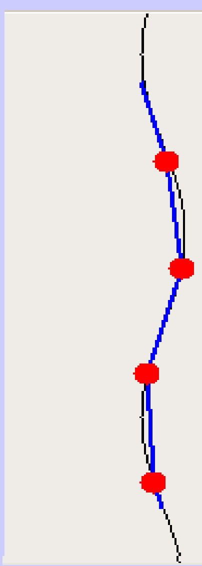
Chain robot 2D:
2D locomotion

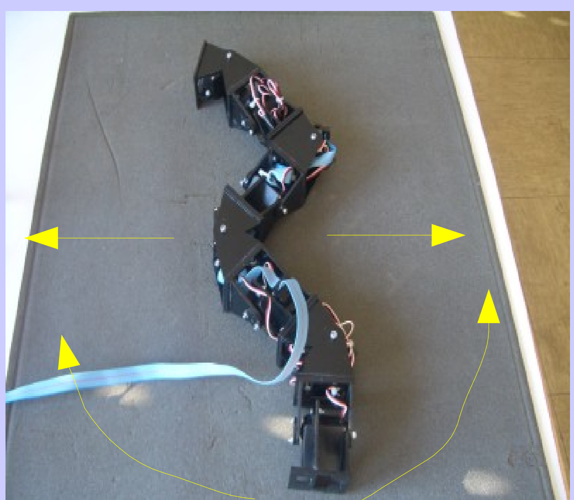
- **Locomotion in 2D**: Lateral shift and rotating

Horizontal wave



Vertical wave

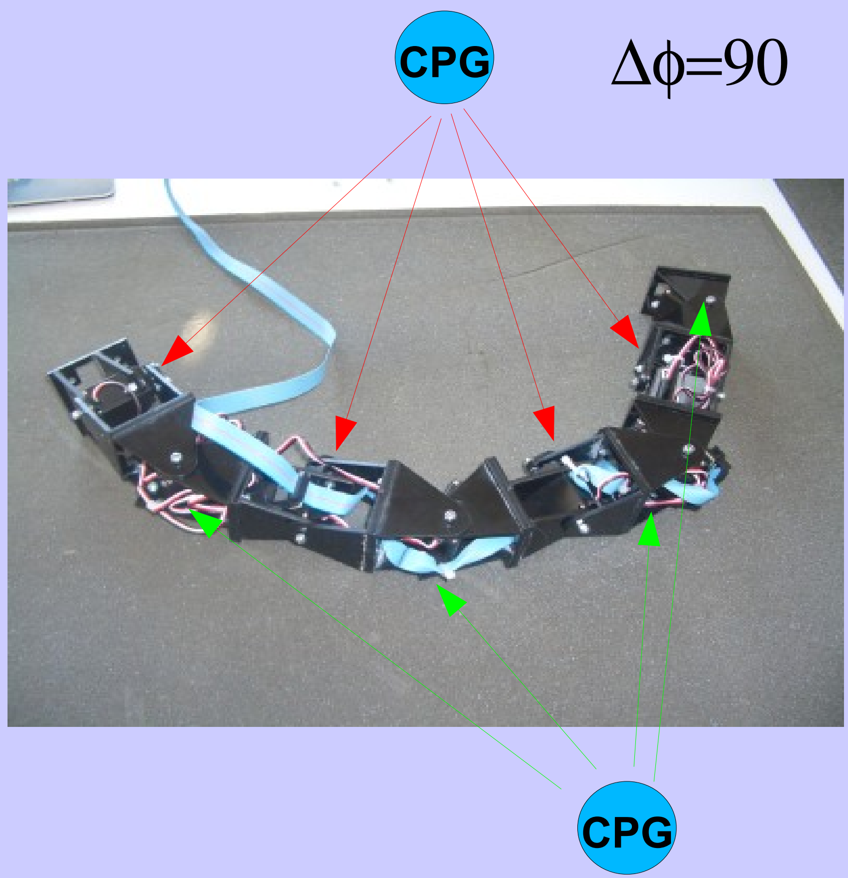




- $\Delta\phi=90$ → Shift right
- $\Delta\phi=-90$ → Shift left
- $\Delta\phi=0$ → Anti-clockwise rotation
- $\Delta\phi=180$ → Clockwise rotation

Chain robot 2D:
Lateral rolling

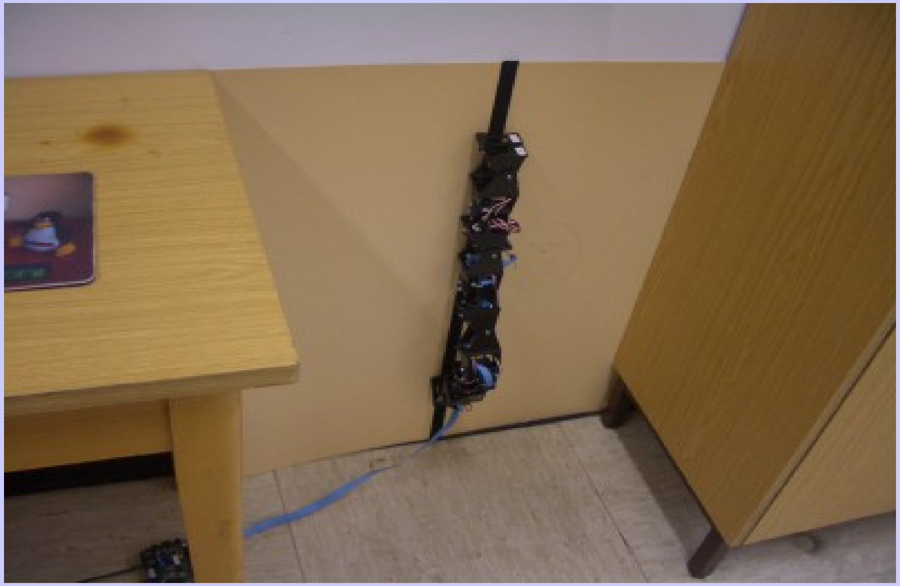
- Two CPGs are used for vertical and horizontal modules
- The phase difference between them is 90 degrees
- The robot rotates about its body axis



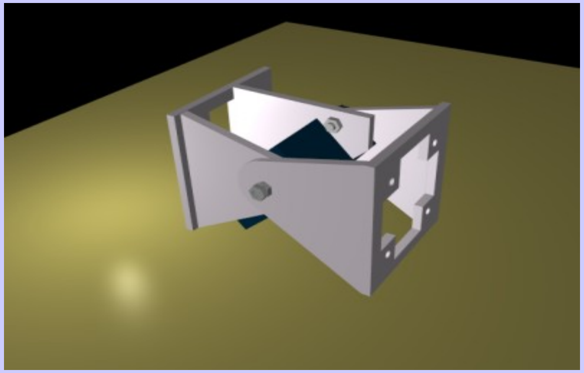
Demo

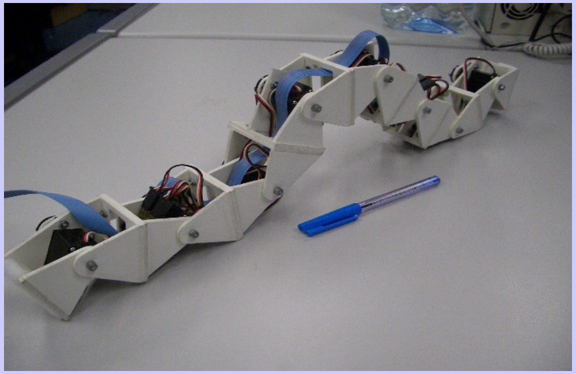
Future work

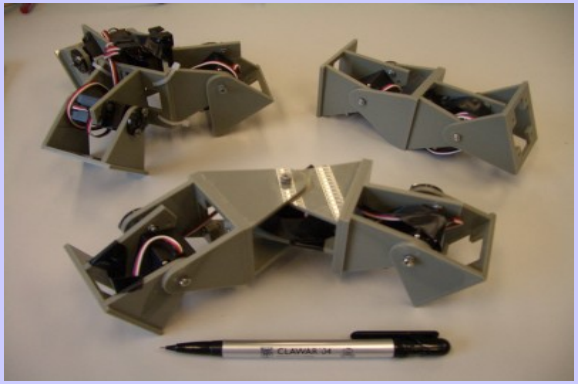
- **Minimal configurations**:
  - What is the 3D minimal configuration?
- **Climbing tests**:
  - What is the minimal configuration for climbing?
  - What are the parameters of the CPGs or global waves to make the robot climb?



Modular robotics and locomotion







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