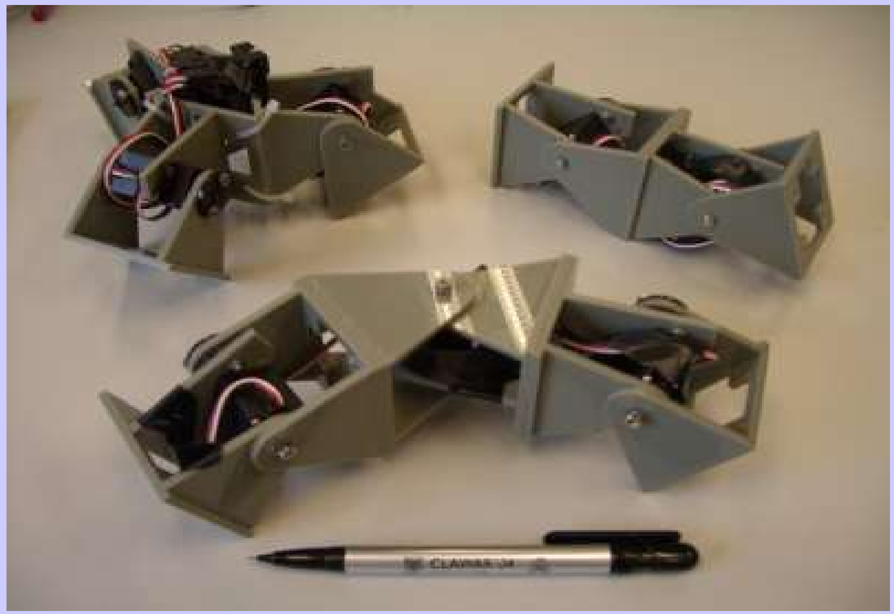
Motion of Minimal Configurations of a Modular Robot: Sinusoidal, Lateral Rolling and Lateral Shift



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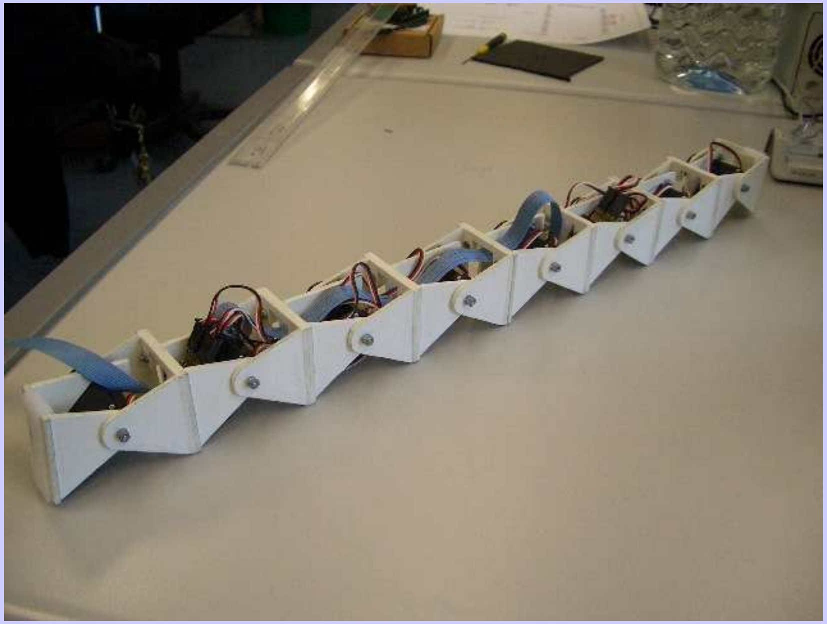
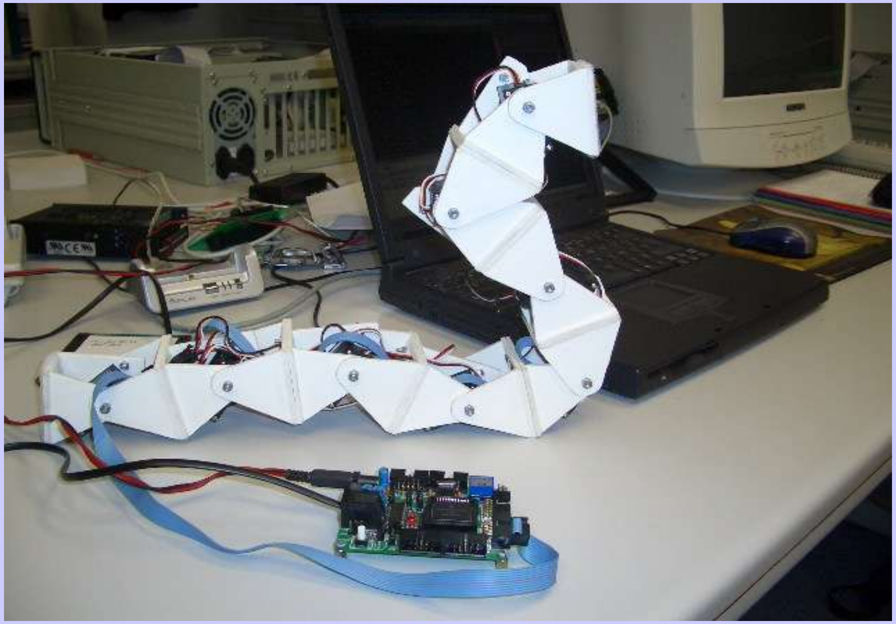
Introduction (I): Previous work

• In Clawar 2004 we presented the **Cube Revolutions** worm-like robot



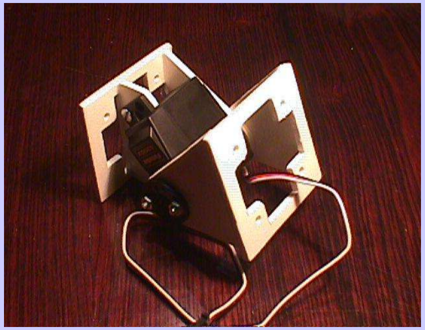


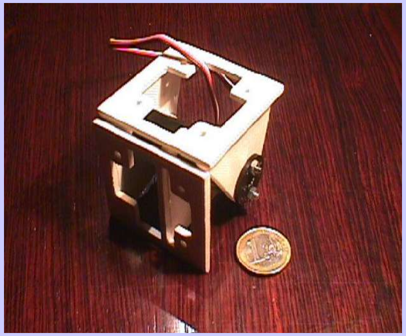
• It is constructed by 8 similar modules, connected in the same orientation

• It only could move along a straight line, using a 1D sinusoidal gait

Introduction (II): Modules Y1

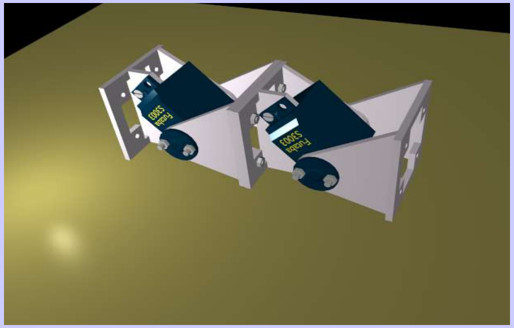
• We designed a one-degree-of-freedom module, very cheap and easy to construct





• Two modules can be attached one to each other in two ways:

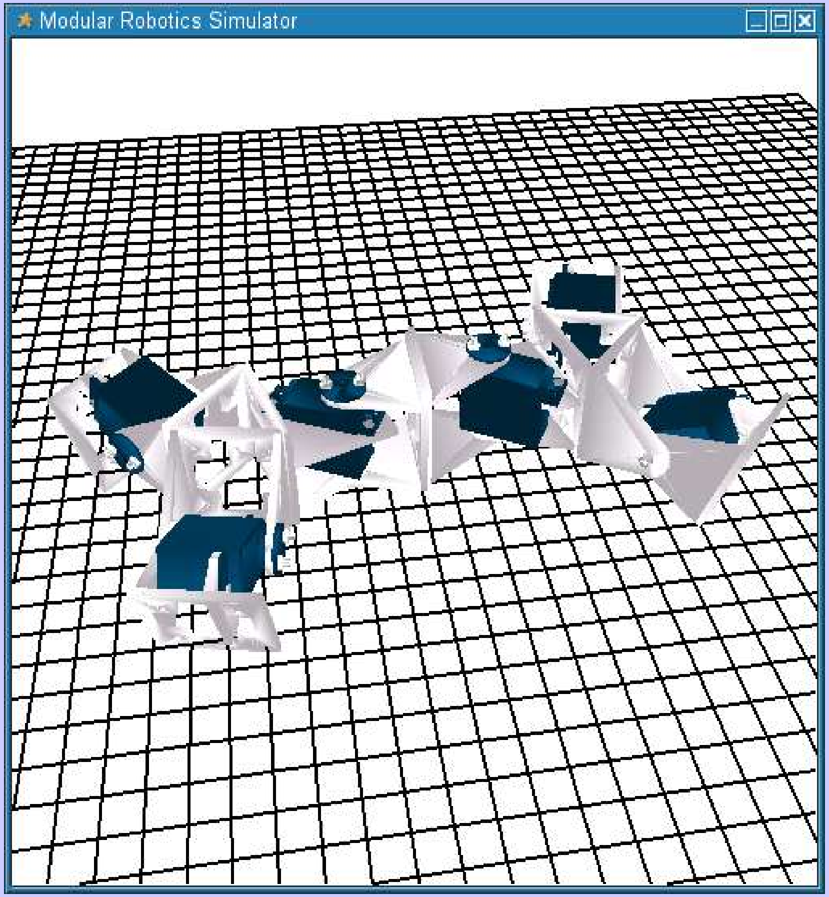
Connection in the same orientation



One module move about the pitch axis and the other about the yaw axis

Introduction (III): Goals

- Complex robots can be constructed by attaching these modules
- But, what we wonder is:

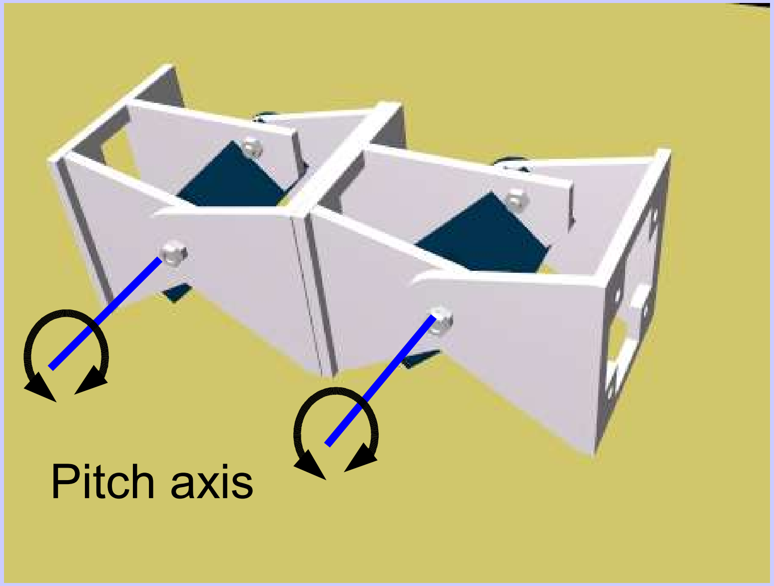


What is the minimum number of modules needed to achieve locomotion in 1D and 2D?

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

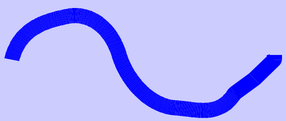
- In order to answer these questions, we have constructed three prototypes

Configuration I (Pitch-Pitch) Description

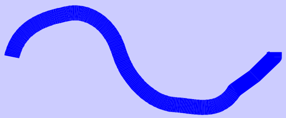


- We call it Pitch-Pitch configuration (PP)
- Two modules connected in the same orientation
- They both move about the pitch axis
- 1D sinusoidal gait

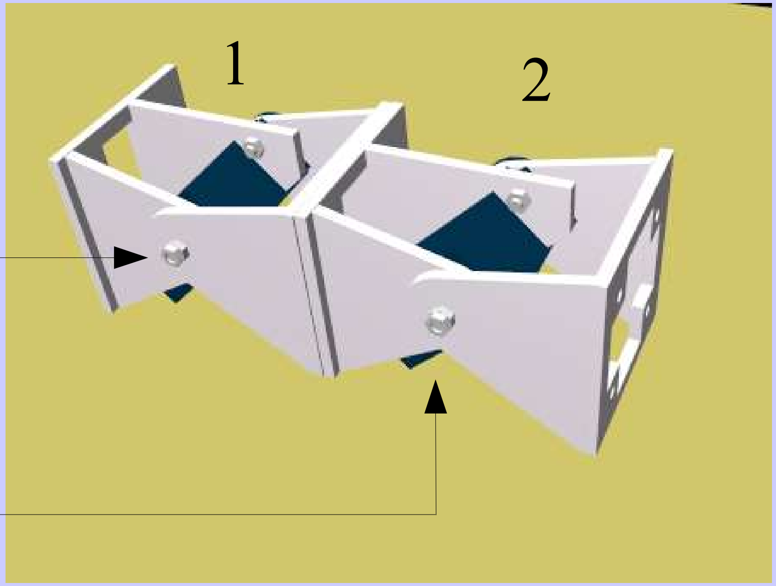
Configuration I (Pitch-Pitch)
Coordination



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

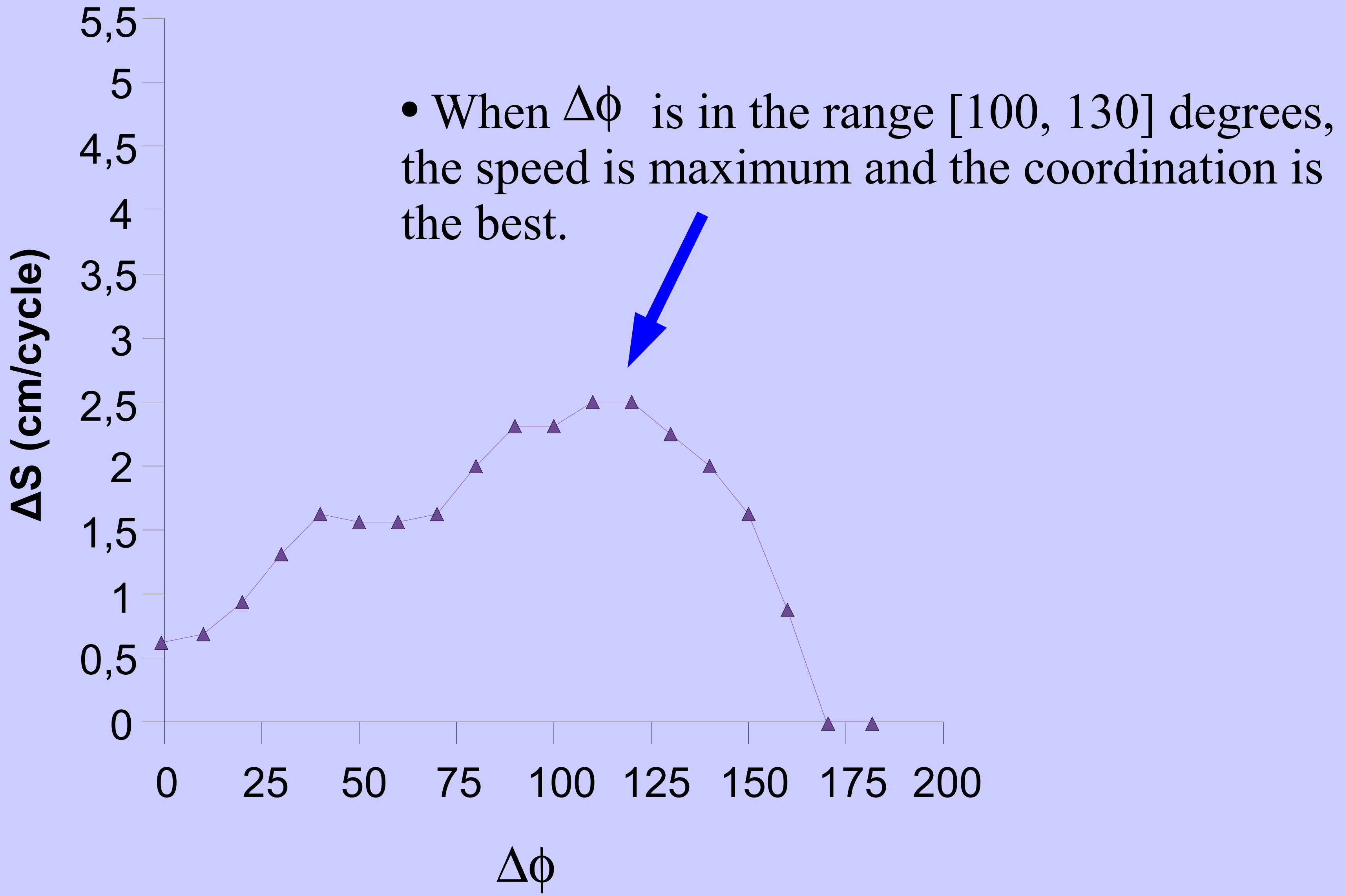


$$\varphi_2 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi\right)$$

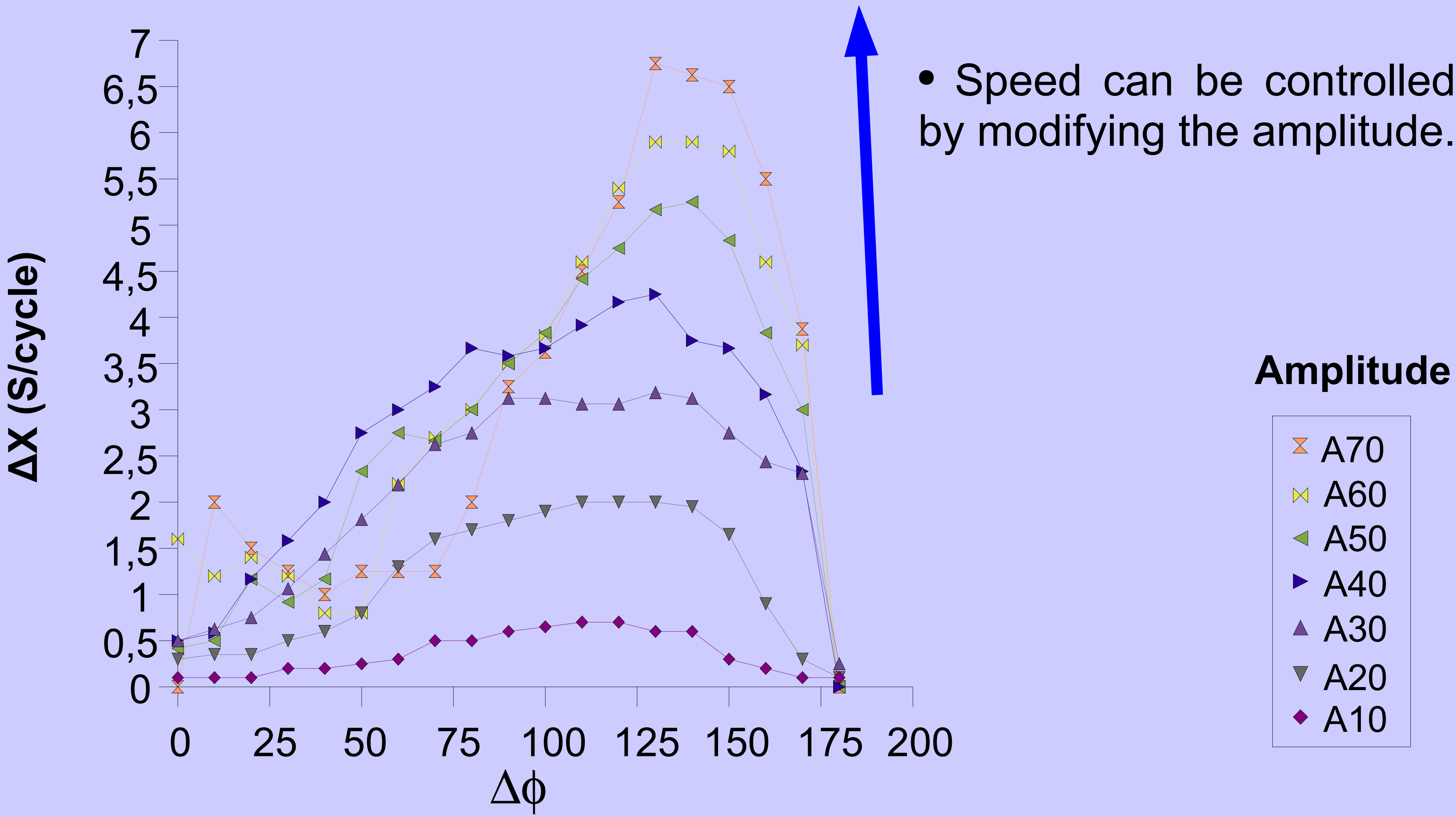


- Two sinusoidal waves are applied to each articulation
- These waves only differ on the phase ($\Delta\phi$)
- $\Delta\phi$ determines the coordination of the movement

Configuration I (Pitch-Pitch)
Results



Configuration I (Pitch-Pitch)
Results



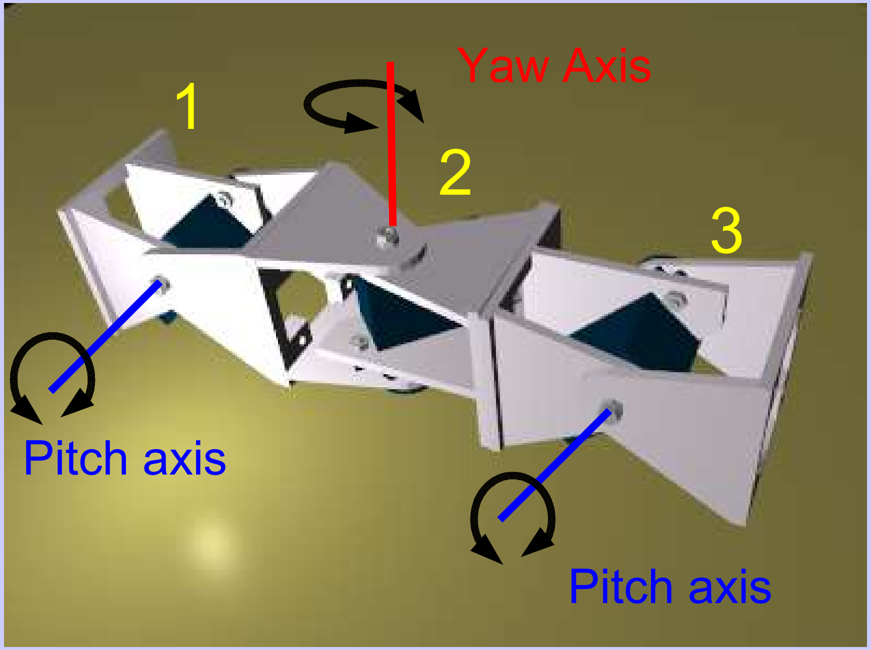
- Speed can be controlled by modifying the amplitude.

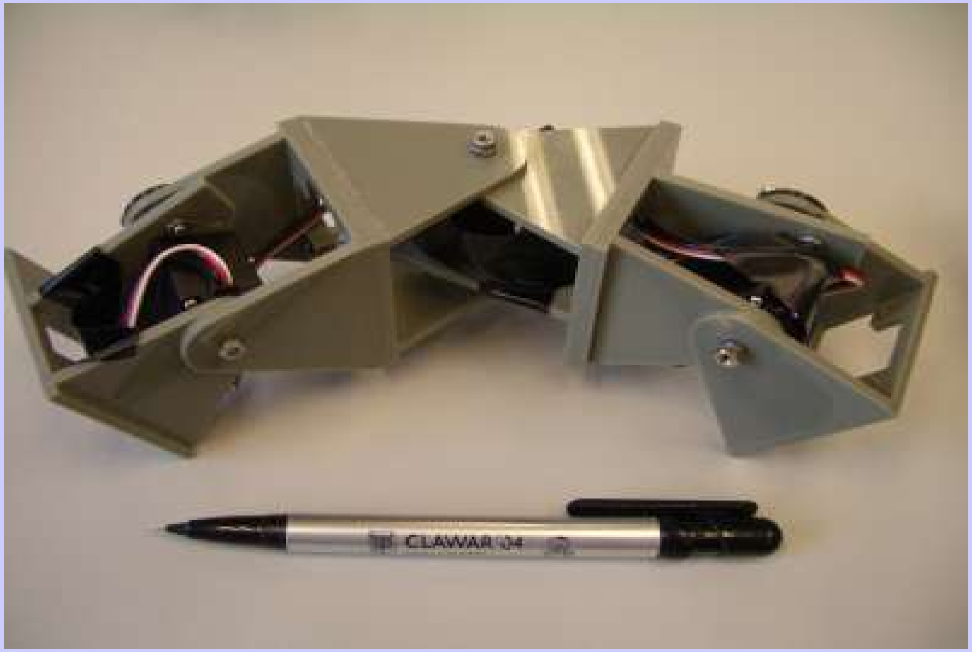
Configuration I (Pitch-Pitch)
Brief summary

1D Sinusoidal gait

- **Minimum number of modules** needed: 2
- Best coordination is achieved when: ∞//ℜ $\Delta\phi$ ℜ∞∋/
- The **sign** of $\Delta\phi$ determines the sense of the movement
- The **speed** can be controlled modifying the **amplitude**

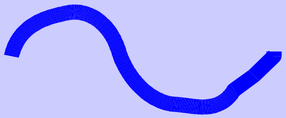
Configuration II (Pitch-Yaw-Pitch) Description





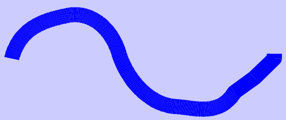
- Three modules: two rotating in the pitch axis and one in the yaw
- We call it Pitch-Yaw-Pitch configuration (PYP)
- 1D and 2D sinusoidal gait
- Lateral shift gait
- Lateral rolling gait

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

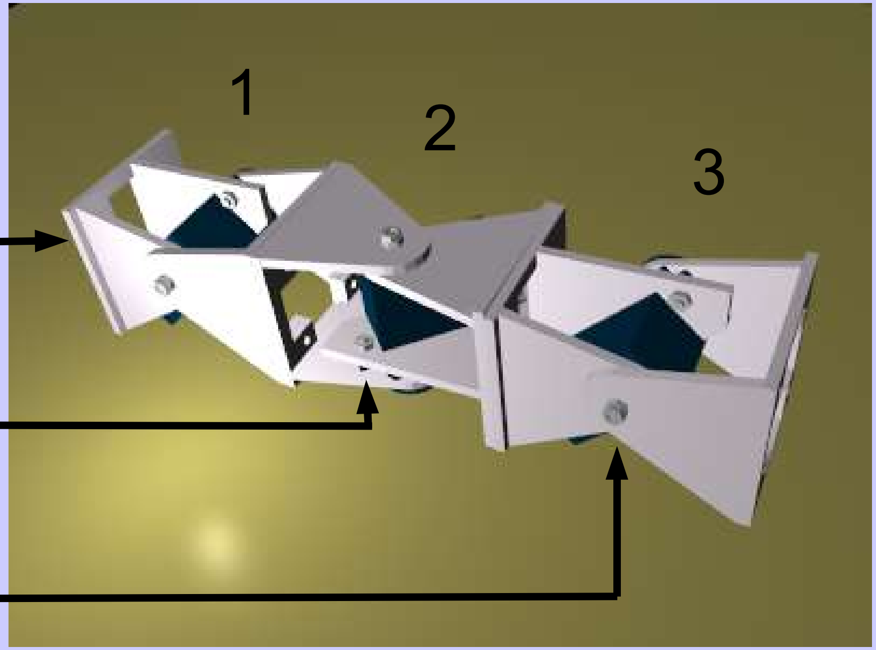


$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$

$$\varphi_2 = 0$$

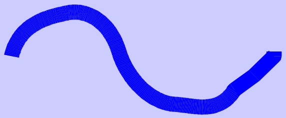


$$\varphi_3 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi\right)$$



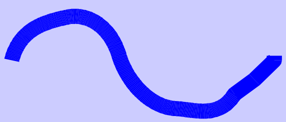
- The angle of articulation 2 fixed to 0 degrees
- Articulations 1 and 3 coordinated in the same way that in the PP configuration
- Sames results as in configuration PP

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

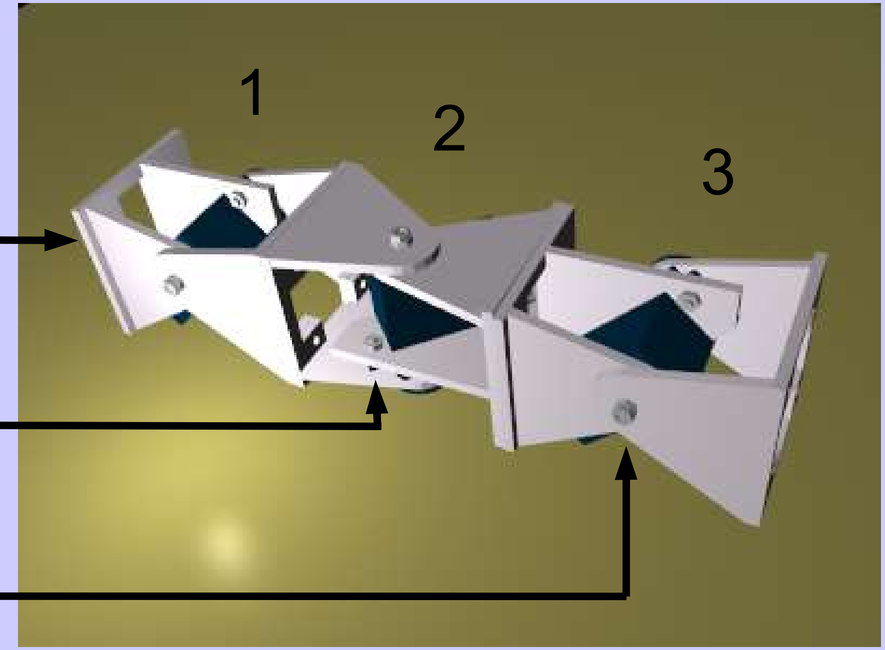


$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$

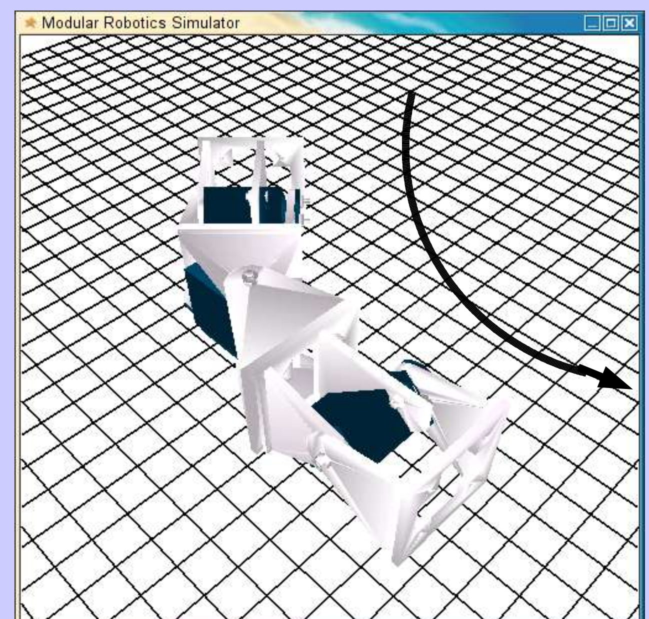
$$\varphi_2 \neq 0$$



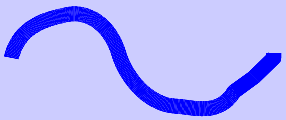
$$\varphi_3 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi\right)$$



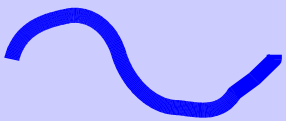
- The same as in 1D sinusoidal gait, but the angle of articulation 2 different from 0 degrees
- The trajectory of the robot is an arc



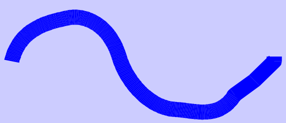
Configuration II (Pitch-Yaw-Pitch)
Lateral shift gait



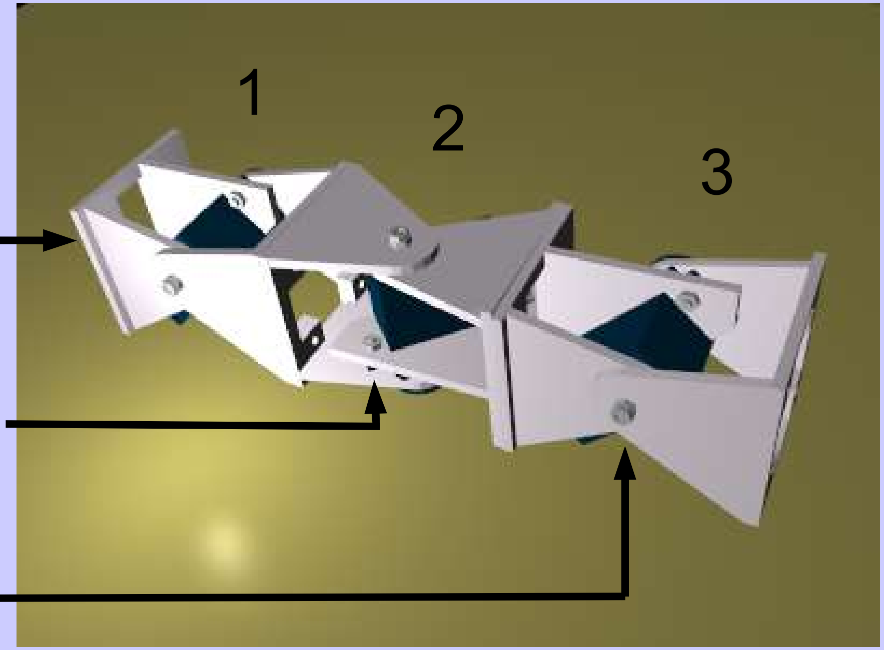
$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$



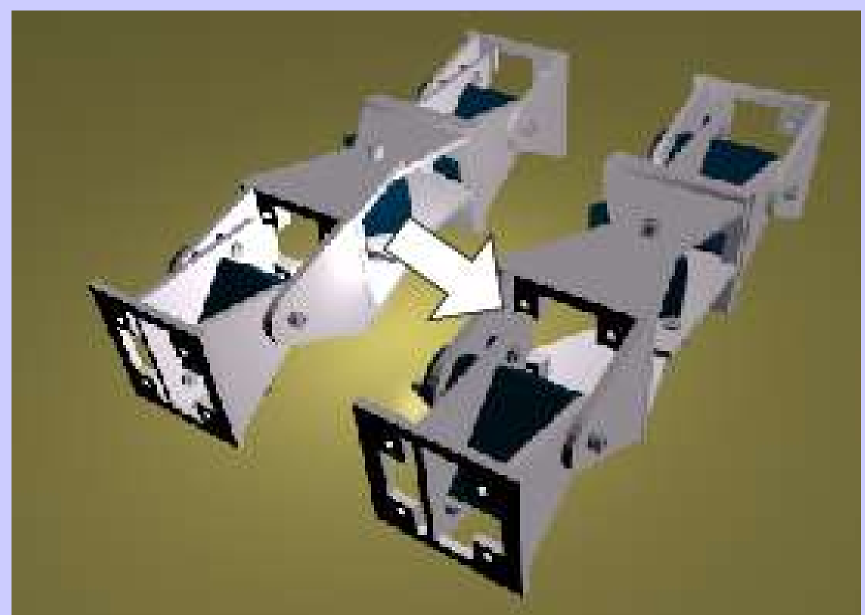
$$\varphi_2 = A\sin\left(\frac{2\pi}{T}t + \frac{\pi}{2}\right)$$



$$\varphi_3 = \varphi_1$$

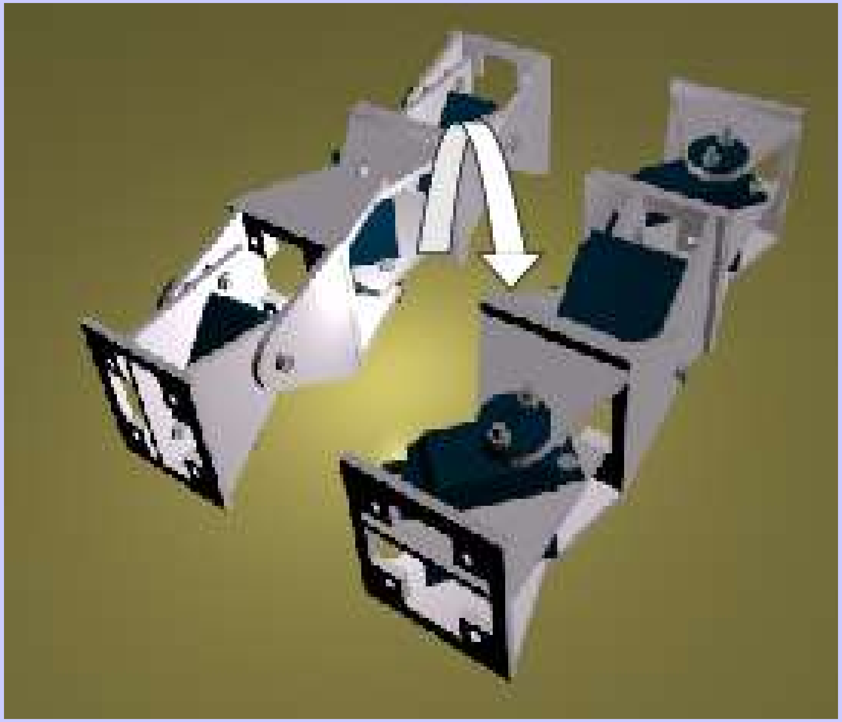


- **A<=40**
- Module 1 and 3 are in phase
- Module 2 is 90 degrees out of phase
- The robot moves parallel to its body axis



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

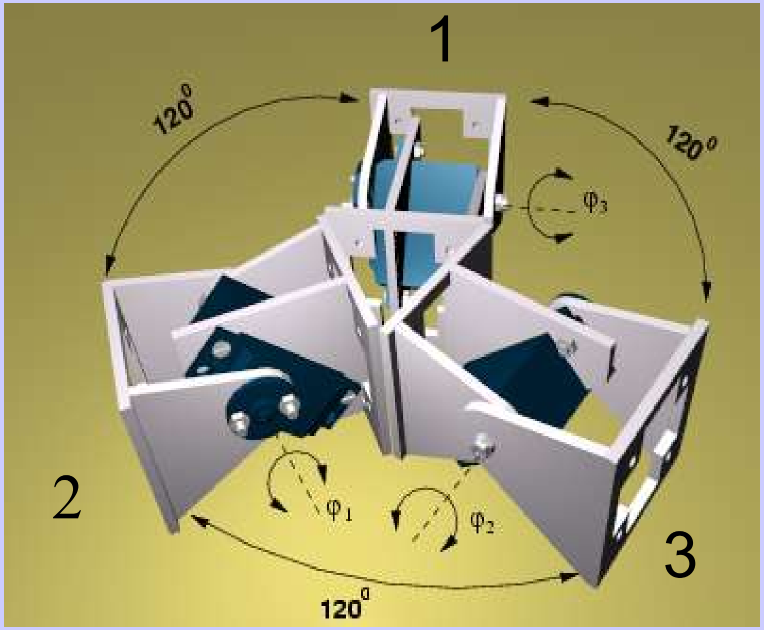
- The same coordination as in the lateral shift gait, but using and amplitude A>60 degrees.
- The sense of rolling can also be controlled by changing the sign of the difference of phase
- The robot rolls about its body axis

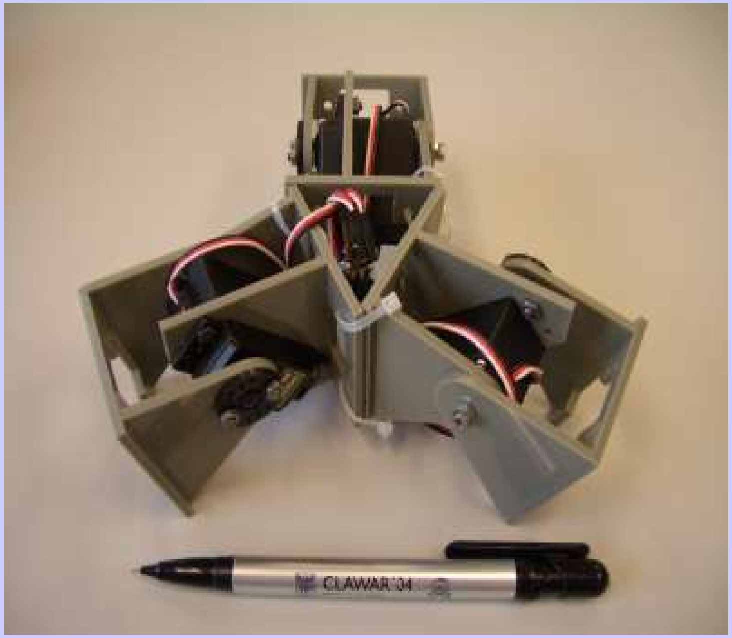


Configuration II (Pitch-Yaw-Pitch)
Brief summary

	1D sin.	2D sin	Lateral shift	Lateral rolling
φ_1	$A\sin(\frac{2\pi}{T}t)$	$A\sin(\frac{2\pi}{T})$	$A\sin(\frac{2\pi}{T}t)$	$A\sin(\frac{2\pi}{T}t)$
φ_2	0	$\neq 0$	$A\sin(\frac{2\pi}{T}t+\frac{\pi}{2})$	$A\sin(\frac{2\pi}{T}t+\frac{\pi}{2})$
φ_3	$A\sin(\frac{2\pi}{T}t+\Delta\phi)$	$A\sin(\frac{2\pi}{T}t+\Delta\phi)$	φ_1	φ_1
$\Delta\phi$	[100,130]	[100,130]	$\frac{\pi}{2}$	$\frac{\pi}{2}$
A	>0	>0	<40	>60

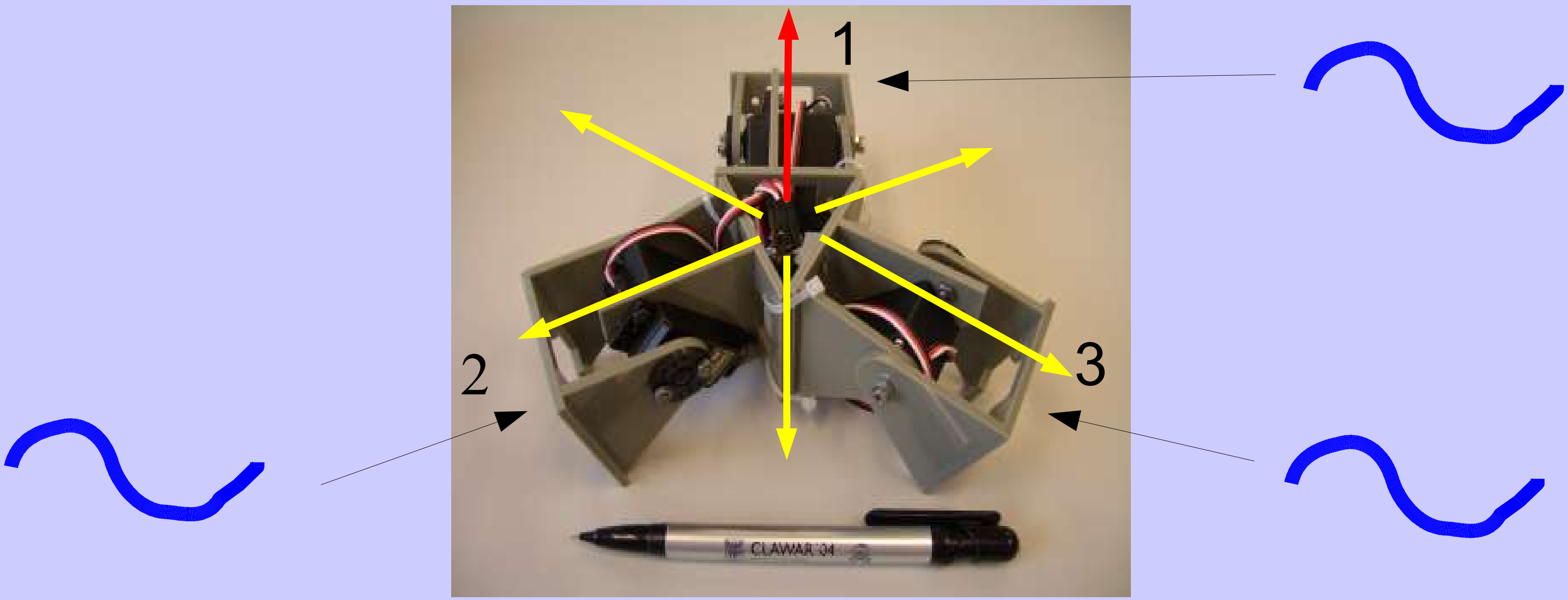
Configuration III: three-modules star Description





- 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

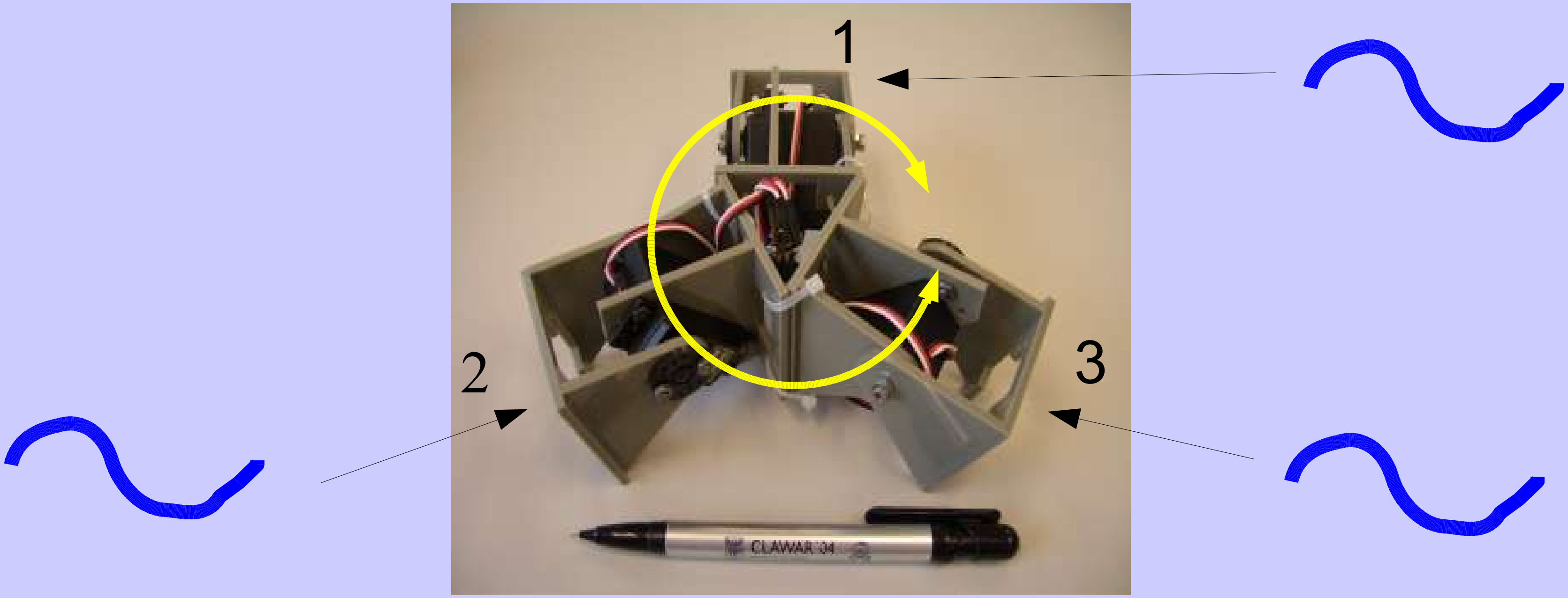
Configuration III: three-modules star
1D sinusoidal gait



- 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

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

Let's see some videos....

Conclusions and future work

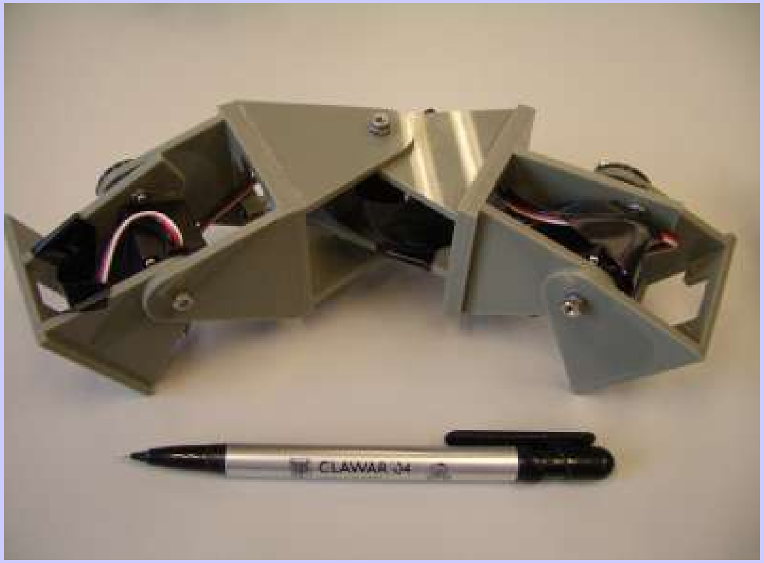
- Only two modules are needed to perform 1D sinusoidal gait.
- Adding only one more module, three new gaits appear: 2D sinusoidal gait, lateral shift and lateral rolling.
- In general, although the gaits are different, the coordination of the modules is very similar.

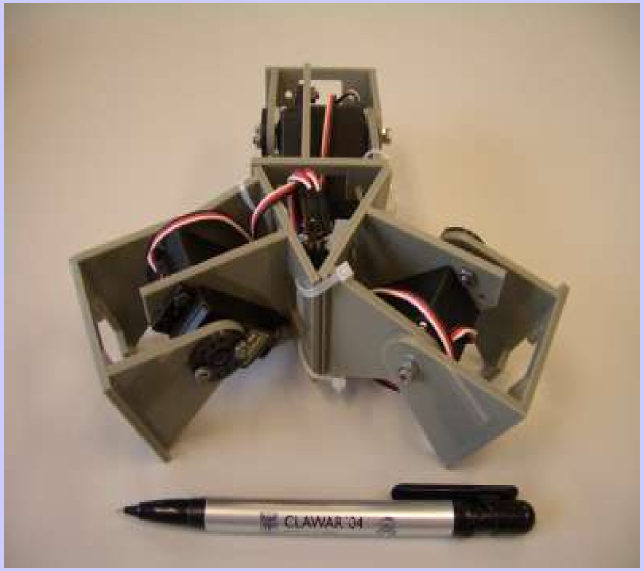
Further work

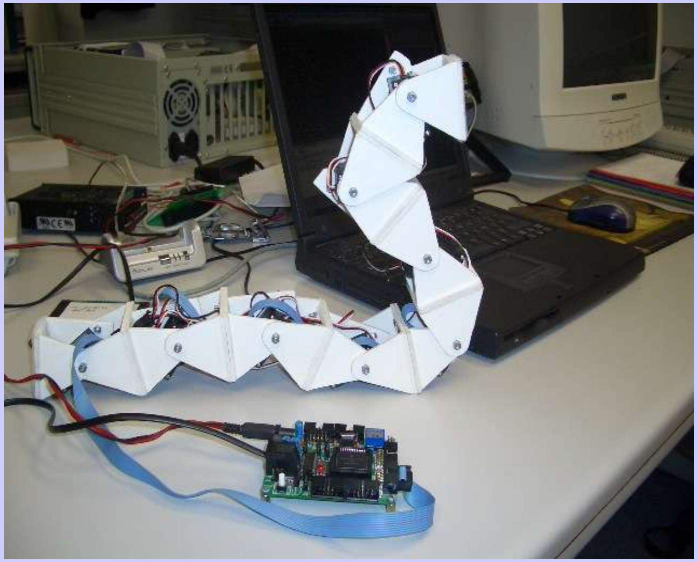
- The construction of a new snake robot capable of moving on 3D
- Generation of gaits using genetic algorithm

THANK you for your attention

I apologize for my bad English :-(







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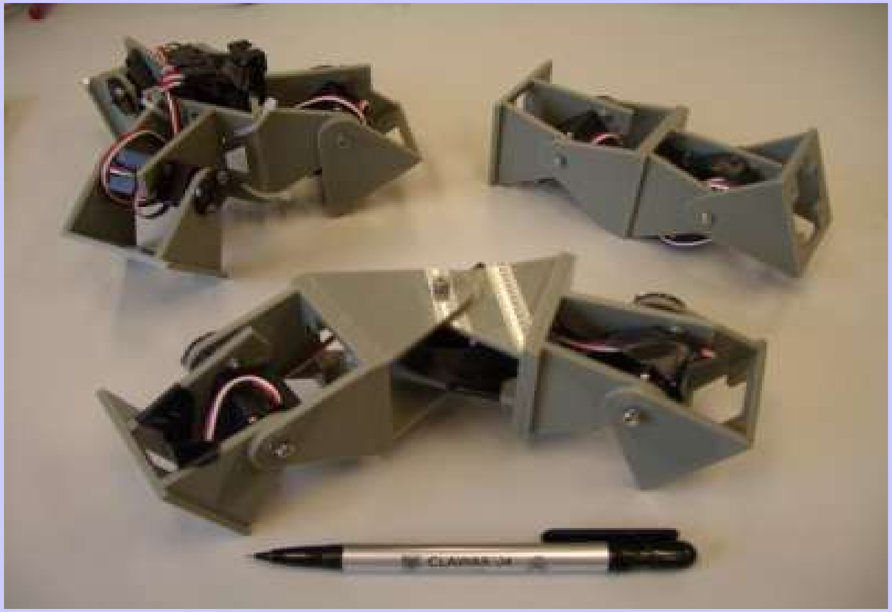

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