ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

BIOLOGICALLY INSPIRED
ROBOTICS GROUP (BIRG)

Master Project

Centipede Robot Locomotion

Brian Jiménez García
[brian.jimenez@epfl.ch]
Supervisor: Auke Jan Ikspeert

Biologically Inspired Robotics Group (BIRG)
Swiss Federal Institute of Technology Lausanne (EPFL)

Outline (I)

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Outline (II)

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- Doubling the robot length
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- Complex terrain: comparison(I and II)
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Introduction: why a centipede robot?

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- A priori, the centipede robot seems to be a natural evolution of the salamander robot architecture.
- Centipede architecture has been used many times, but projects were not focused on evaluating the possible locomotion gaits obtained with this architecture.
- Interesting biological questions concerning real centipedes could be studied.

Goals and objectives

- Evolving salamander robot architecture increasing the number of legs and adding new degrees of freedom (DOF).
- To adapt the architecture to complex terrain constraints.
- Testing different locomotion gaits with a chosen architecture over flat and complex terrain via an oscillatory controller.

Centipede Robot: Beyond nature

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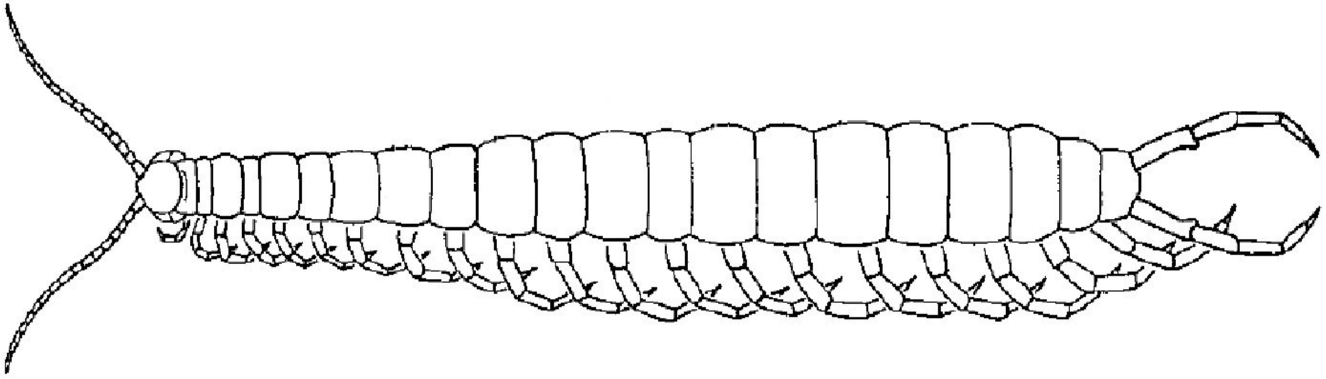
In nature:

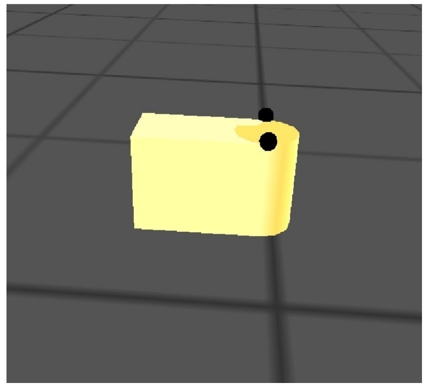
- 2 legs per segment.
- Unequal segment size.
- From 15 segments to up to 170.

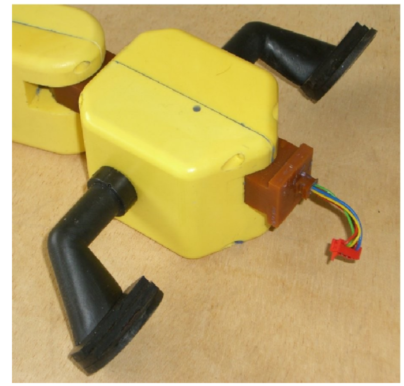


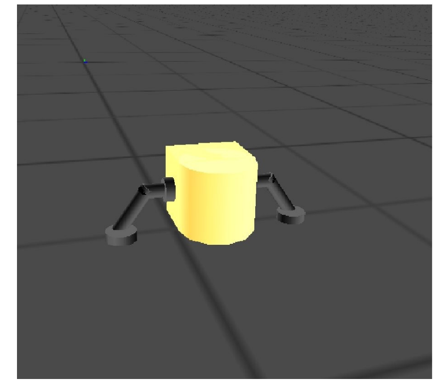
Scolopendra heros **(video)**

Centipede robot: architecture

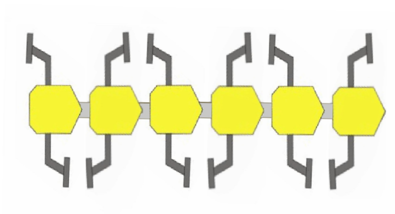
- Based in salamander robot modules.



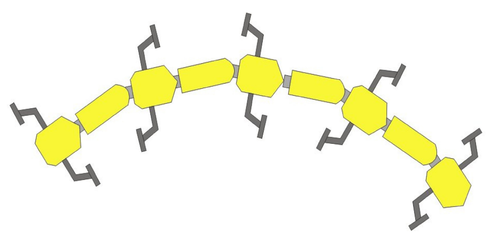




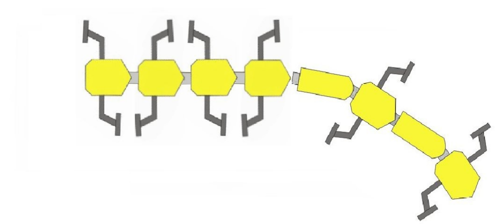
- Three main types



Only limbs



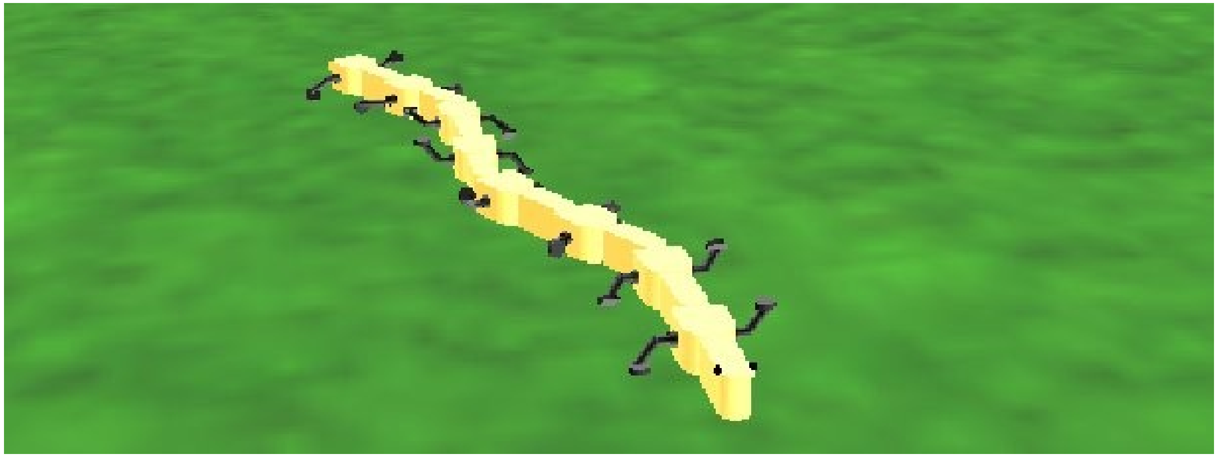
Limbs-body



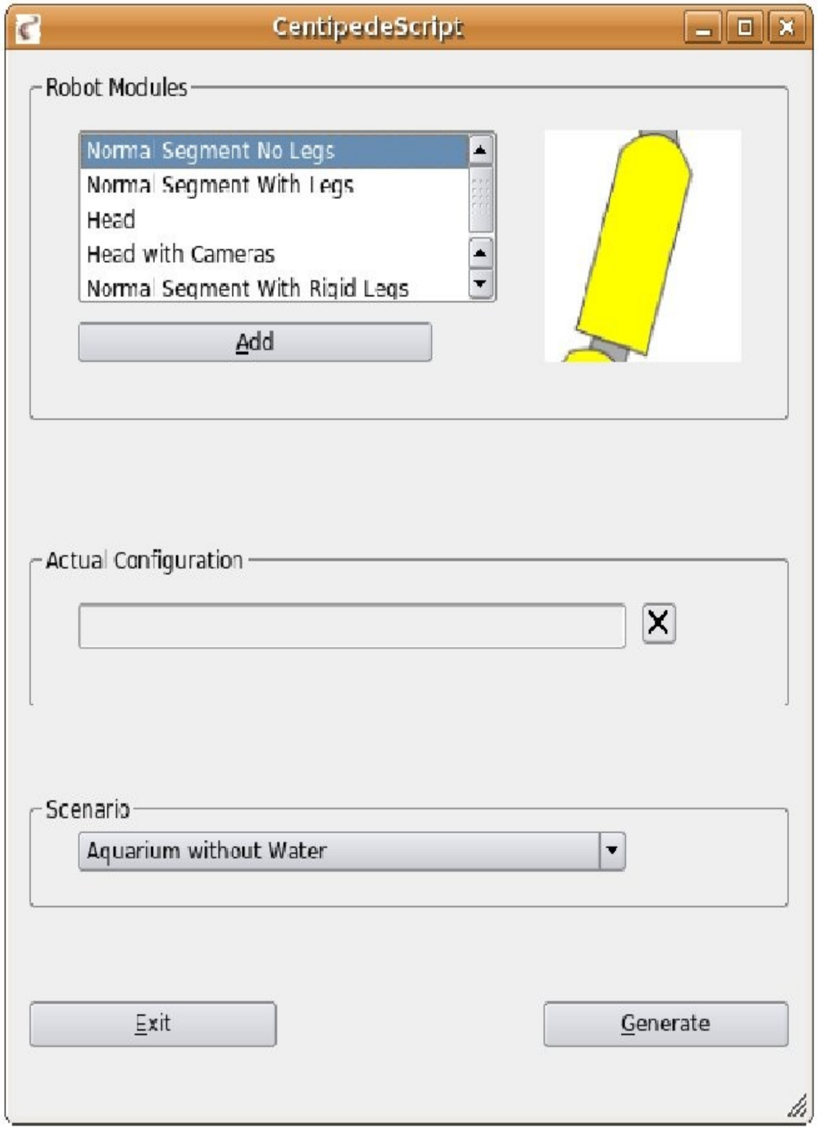
Mixed

Centipede Robot: CentipedeScript(I)

- Experiments in Webots© platform.
- A tool for fast designing of centipede-shape models has been coded: CentipedeScript.
- Written in C++ and using Trolltech Qt 3.0 libraries.
- Easily extensible and cross-platform.



Centipede Robot: CentipedeScript(II)



Video

Fixing the architecture

- Eight legs or more. Interested in models different from hexapods.
- Aliasing. Starting from 8-legs, a sufficient number of legs is needed to avoid this effect.
- Reasonable robot length:

16 legs, 16 modules,

8 limbs modules, 7 body modules, 1 head

10.2x8 + 9.5x8 = 157.6 cm ~ 1.5 m

Controllers: rigid vs oscillatory

In real scolopendra heros, has been demonstrated that lateral muscles are not resistive to lateral bending, but promoting it. Any improvement in locomotion using an oscillatory controller instead of a rigid one in flat terrain? And in complex terrain?

Rigid Controller

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Legs rotation angle calculated as:

$$\varphi = \omega_{legs} \cdot t$$

$$\varphi_{rightlimbs} = \varphi + \phi_r + \phi \cdot i$$

$$\varphi_{leftlimbs} = \varphi + \phi_l + \phi \cdot i$$

Where:

- ω: angular speed (legs frequency)
- t: time step
- ϕr and ϕl: initial right and left phase.
- ϕ: phase between legs, variable to be optimized

Oscillatory Controller

Legs rotation is calculated as in the Rigid Controller.

Body module *k* controlled with the expression:

$$f(k) = A_k \sin(\omega \cdot t + \varphi + \Delta\varphi \cdot k)$$

Where:

- ω: angular speed (body frequency)
- t: time step
- φ: phase difference between limbs and body.
- Δφ: phase difference between the modules.
- Ak: amplitude of the servo

Rigid controller in flat terrain

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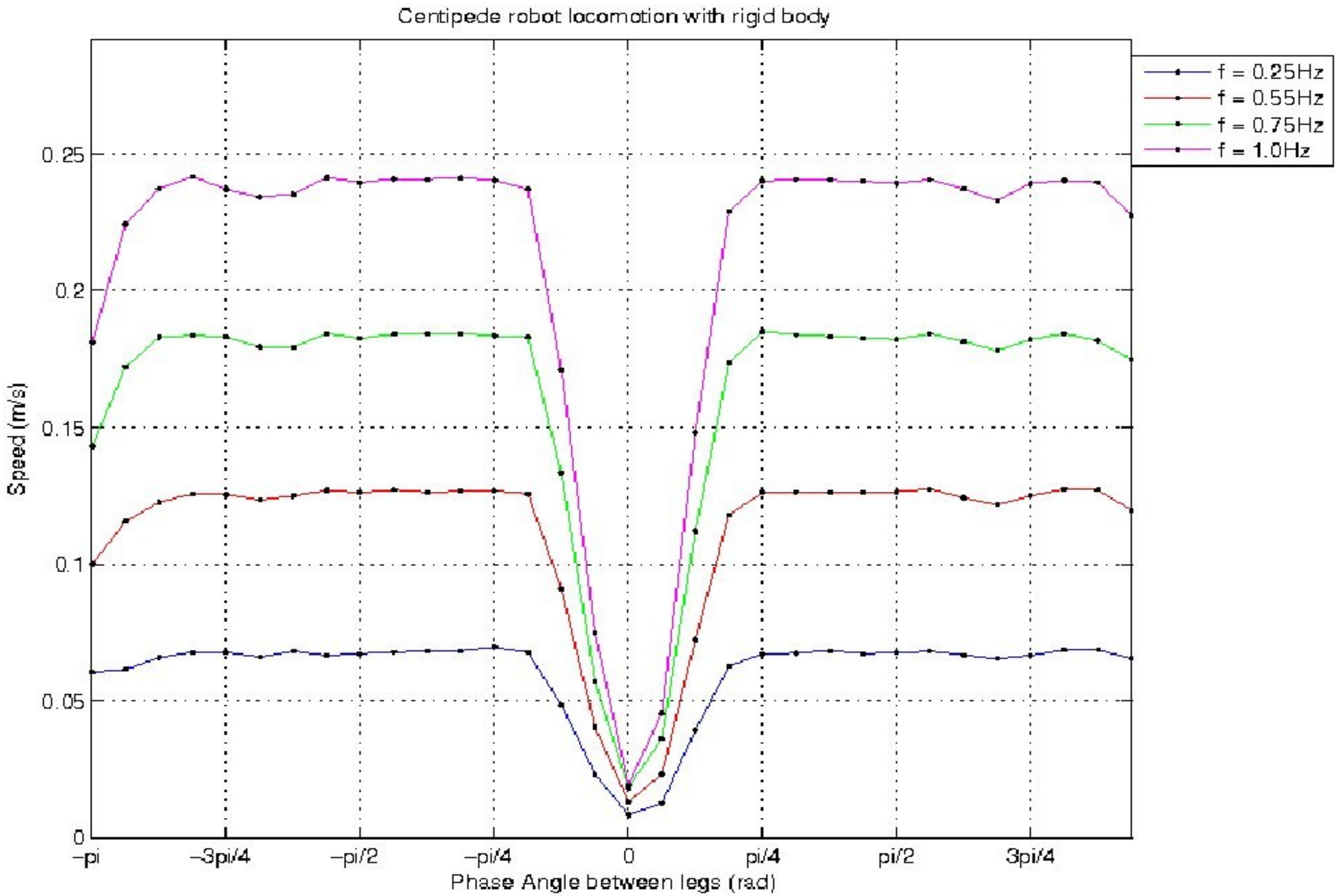
Phase angle between legs versus speed



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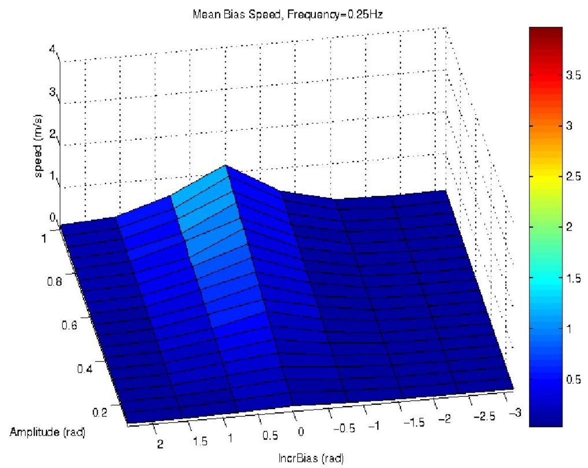
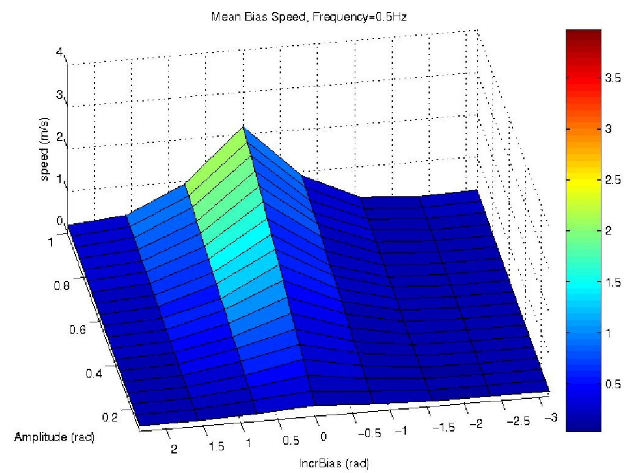
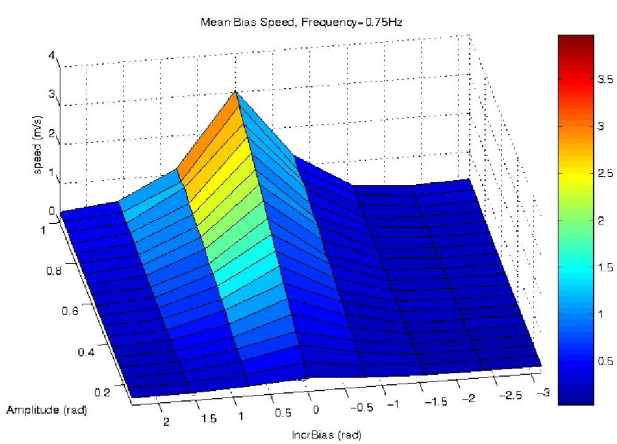
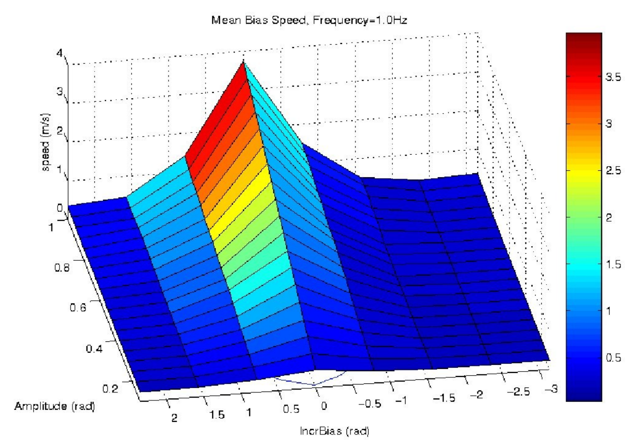
Multiple parameter search









Oscillatory controller corrections

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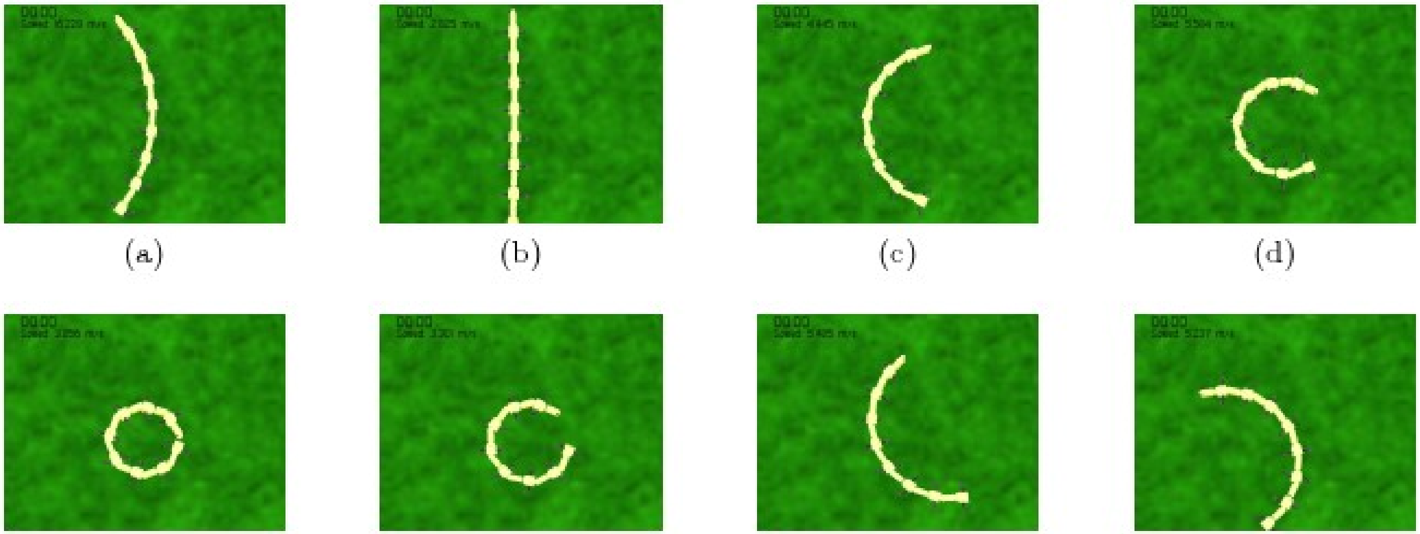
Instant speed is not reliable:



(a) (b) (c) (d) (e) (f) (g) (h)

- Mean speed instead of instant speed.
- Introduction of the straightness tolerance

$$\alpha \in [\frac{\pi - \varepsilon}{2}, \frac{\pi + \varepsilon}{2}]$$

Flat terrain: comparison

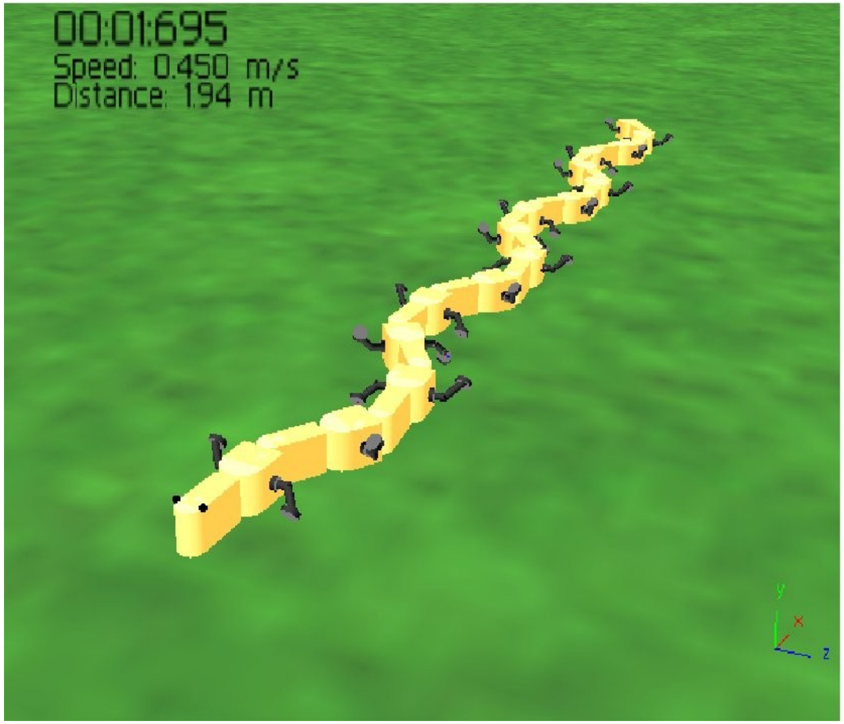
Best solution found with rigid controller:
ϕ: π/2 radians
Best solution found with oscillatory controller:
- φ: 0 radians
- Δφ: -π/2 radians
- Ak: 1.0

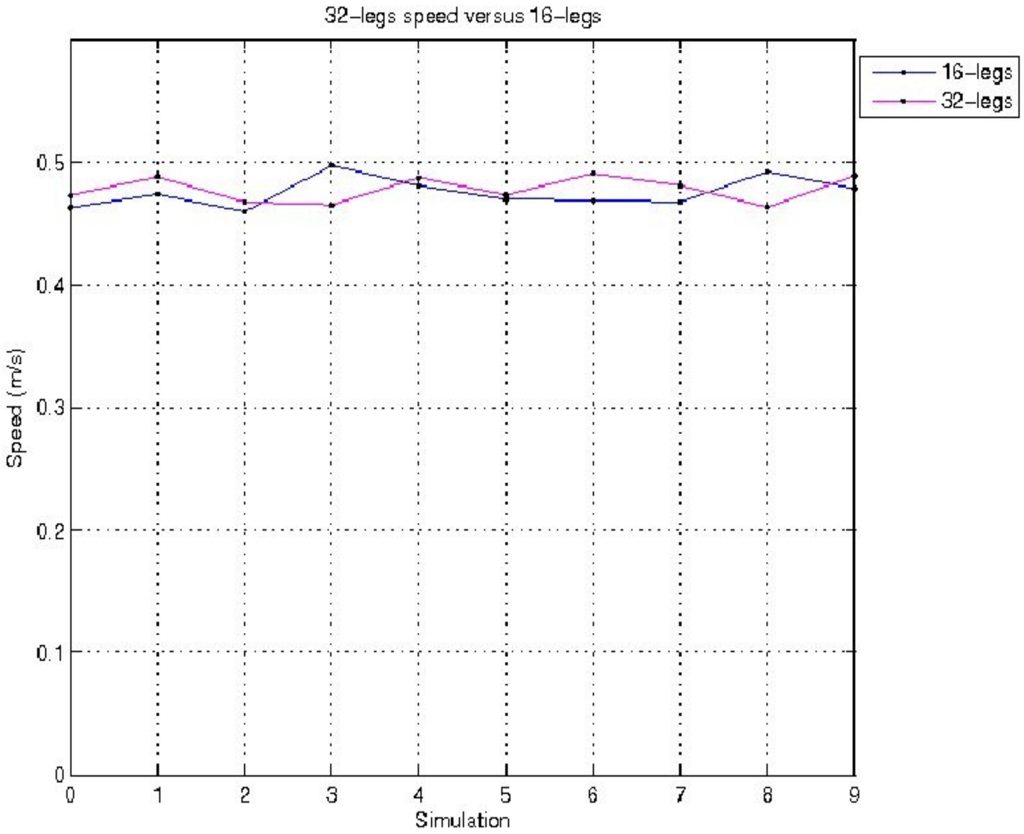
Rigid performance of 0.25 m/s versus Oscillatory performance of 0.45 m/s. Over 85%!

Rigid video   Oscillatory video

Doubling the robot length

What if the robot length is doubled?





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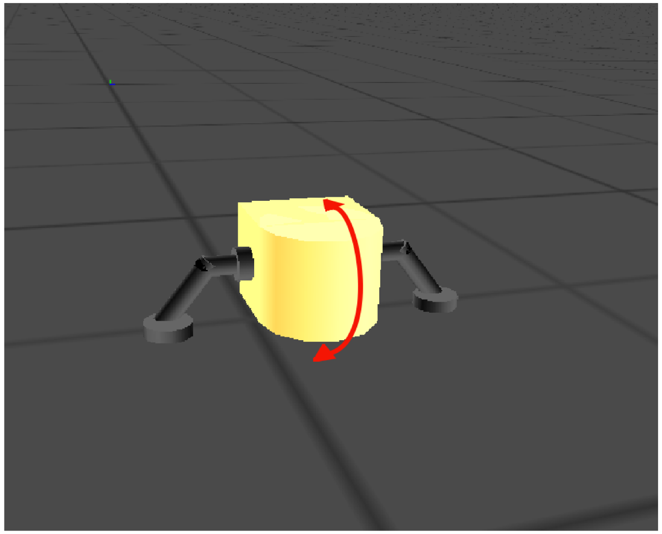
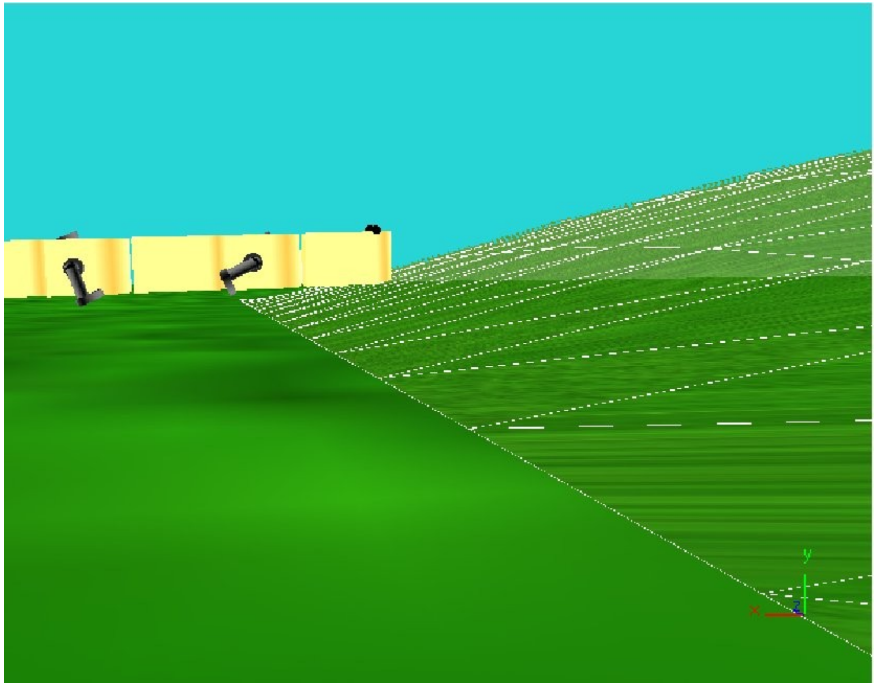
Stiffness problem solved with a new limbs module.

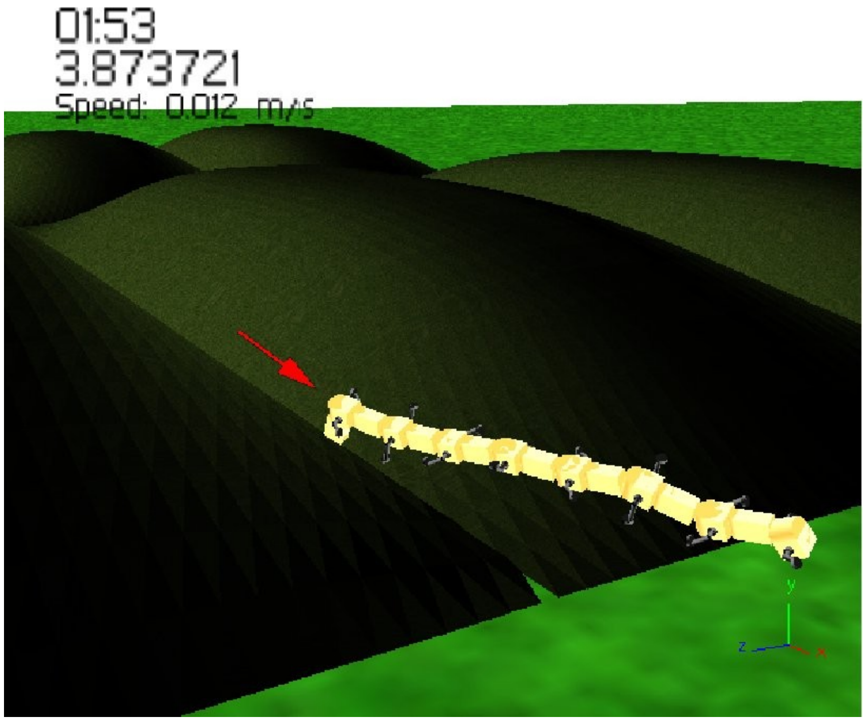
New joint has two possibilities:

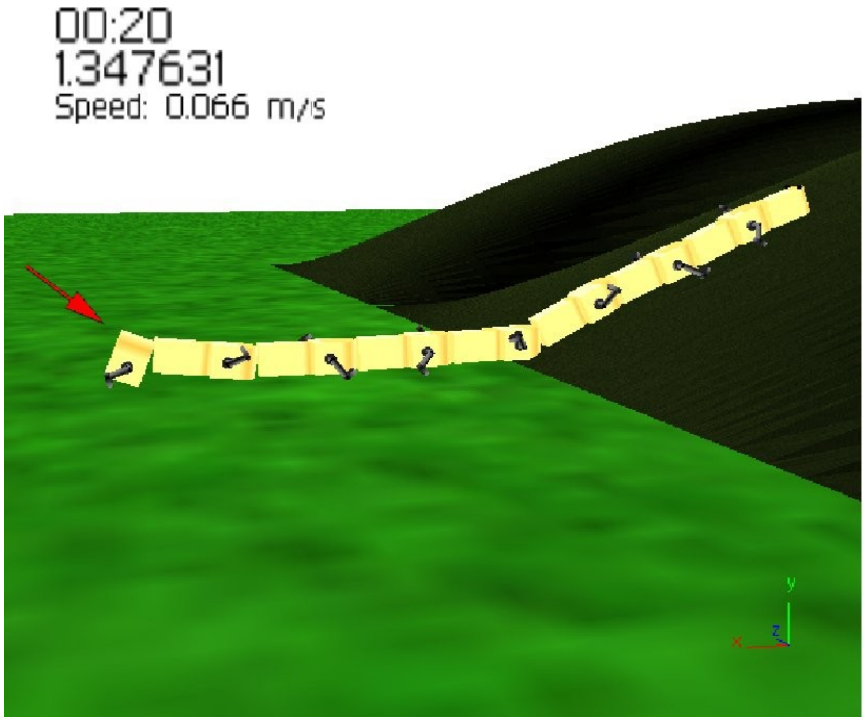




- Totally passive joint
- Spring and damped joint

Totally passive joint introduce new robustness problems: head stuck and tail stuck.





Spring and damped joints

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Spring and damping constant can be tunned to provide sufficient stiffness to climb over objects avoiding totally passive joints problems and incorporating elasticity when is needed (rough terrain).

When spring and damping constant are not tunned conveniently, stability problems appear.

Recommended:

- Big values for the damping constant inside the allowed interval.
- Small values for the spring constant.

Complex terrain: comparison (I)

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After fixing the spring and damping constant, rigid and oscillatory controllers are confronted three different complex terrain scenarios.

For the oscillatory controller, the parameter search is rerun to check which are the most performing solutions.

Best solution found in flat terrain is the most performing one again in complex terrain!

Complex terrain: comparison (II)

Rigid body and oscillatory body performances compared in each complex scenario:

	Rigid Body	Oscillatory Body
Scenario A	3.94	6.37
Scenario B	3.73	6.48
Scenario C	3.43	5.97

Improveness near to 70% using the oscillatory controller.

Robustness though different scenarios and noticeable increase of the performance of the locomotion gait studied.

Conclusions

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- Oscillations along the robot body increases speed.
- Damped and spring joints are the recommended solution to face obstacles and complex terrain.
- Oscillations help climbing obstacles.
- Best solution in flat terrain is the same as in complex terrain.
- Robustness of this solution can be tested even doubling the length of the robot.

Future Work

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The work presented in this master project will aim and encourage the developing of new hardware modules in the salamander robot project scope and has stablish the base for implementing new controllers based in CPG's theory using the good locomotion gaits previously found.

Thanks for your attention!

Questions?

Complex Terrain Interactive Demo