Neuro-Muscular Controller Based on Reflexes and a Central Pattern Generator to Achieve Gait Modulation

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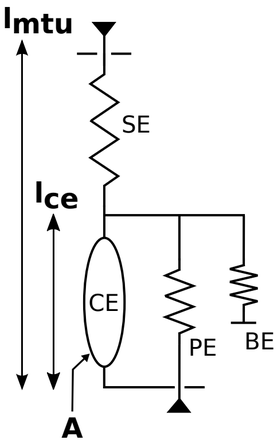
Motivation & implemented algorithms

While classical approaches achieve nice gaits with humanoid robots, we are still far from the **impressive human walking capabilities**.

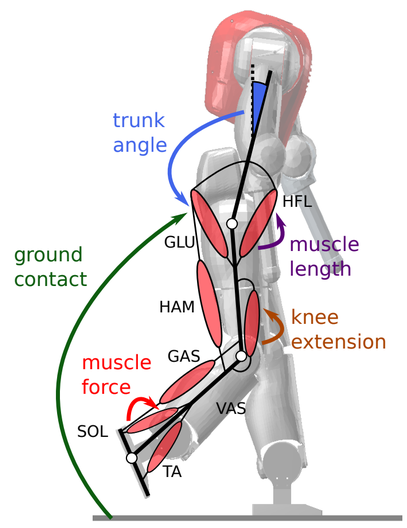
Bio-inspired algorithms are being developed, generating more **energy-efficient** and **human-like** gaits, but they are mostly limited to simulation studies (Geyer and Herr, 2010).

We develop controllers based on **virtual muscles controlled by neuronal stimulations** like reflexes and a central pattern generator.

This is tested on a **full-body humanoid robot**: the COMAN. It also allows to improve our **understanding of human locomotion**.



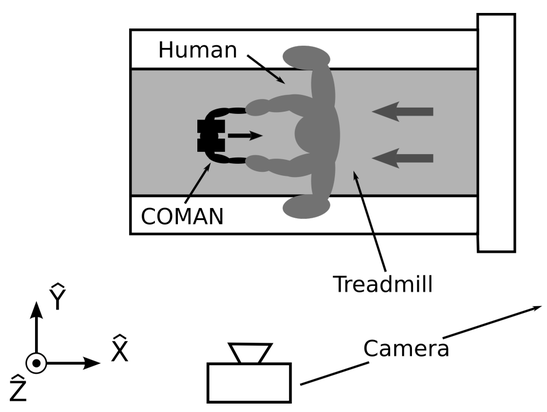
Hill muscle model

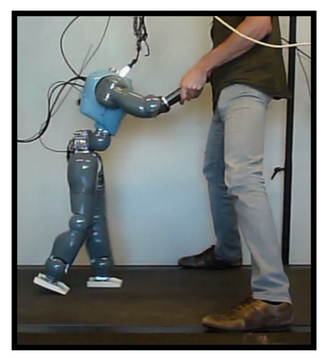


Leg muscles

Experimental setup for 2D cases

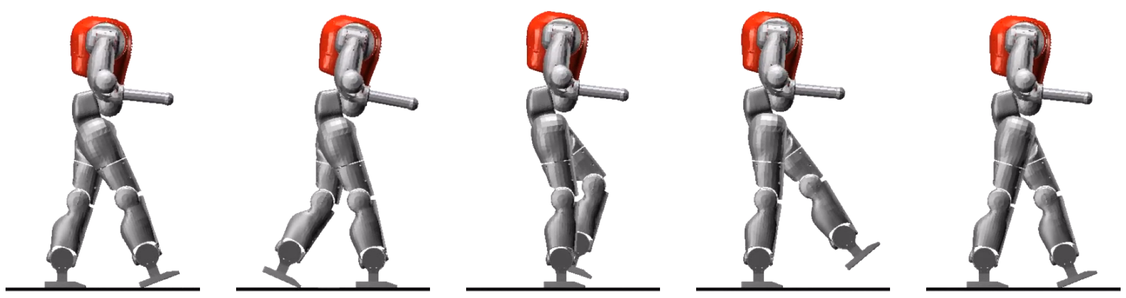
Due to the lack of lateral balance control in 2D scenarios, an **extra upper body controller** is developed to let a human operator provide lateral stability, without affecting the sagittal plane.





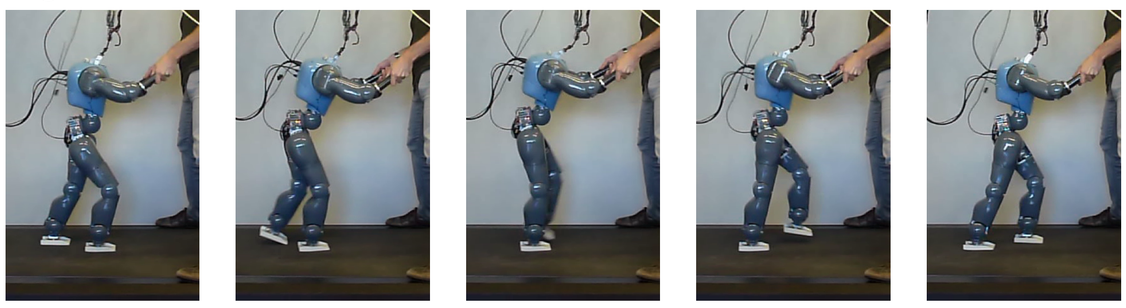
Reflex-based controller - from simulation to real hardware

Simulation gait



t = 0 s | t = 0.2 s | t = 0.4 s | t = 0.57 s | t = 0.73 s

Real gait



t = 0 s | t = 0.37 s | t = 0.57 s | t = 0.8 s | t = 1.03 s

The gait controller is optimized in a **simulation environment**. The objective function rewards solutions minimizing the **metabolic energy** consumption.

The gait controller optimized in simulation is then ported to the **real robot** with no modification.

Similarities with simulation

- stretched stance leg (feature usually absent in most robotic gaits)
- rolling foot at swing initiation

Differences with simulation

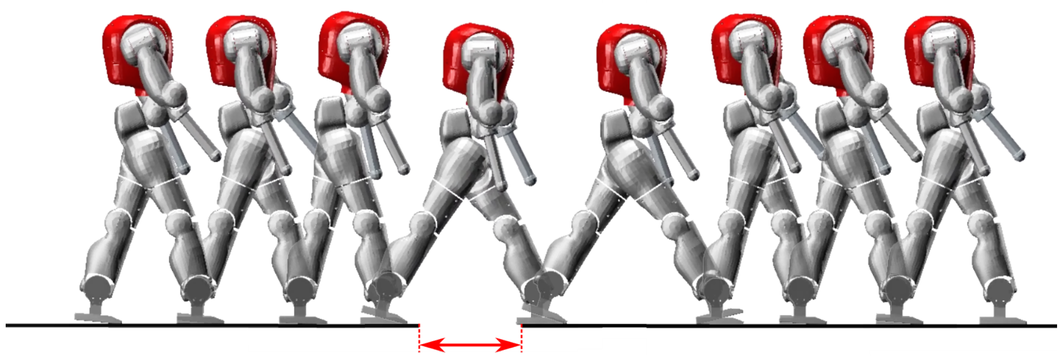
- flexed knee during late swing (due to the **friction effects** in the robot joints)
- shorter steps
- lower step frequency

Despite these huge differences in the walking gait, the robot still manages to walk, demonstrating some kind of **robustness** related to this bio-inspired controller.

Speed and step modulation through CPG

A **Central Pattern Generator** (CPG) is a neural circuit capable of producing rhythmic outputs while receiving simple non-rhythmic input signals.

A **full range of speeds** (0.4 m/s to 0.9 m/s) can be obtained by coupling the reflexes to a CPG. All parameters are co-optimized in one single optimization.



Combining reflexes with a CPG

- Proximal muscles mainly driven by a central pattern generator
- Distal muscles mainly driven by reflex rules

Speed control parameters

- CPG amplitude
- CPG frequency
- Trunk angle reference

Steering modulation in 3D

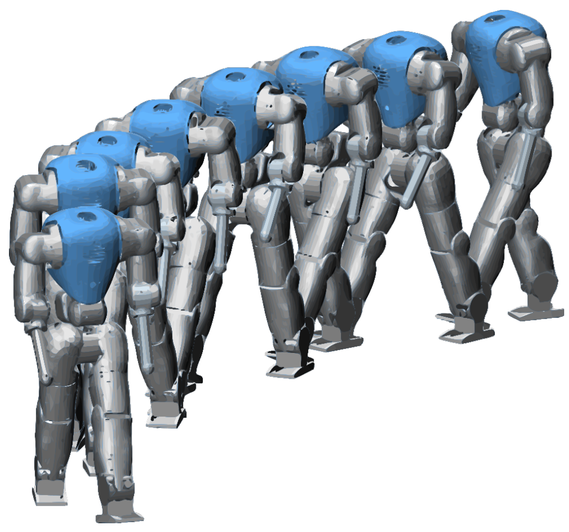
The controller is incremented so that the robot motion can be **controlled online** in a **3D environment**.

Extension to 3D scenarios

- Release lateral constraints
- Increment both reflex rules and CPG structure

Control with two joystick axes

- Speed control in a range similar to the one obtained in 2D
- Steering direction (left or right) and radius



Comparison to traditional controllers

- Intensive offline optimizations, but **cheap computation** during locomotion
- Interesting tool to better understand **real human locomotion**
- Gaits closer to human ones
- Higher **speeds**
- Lower **energy** consumption

Acknowledgment & References

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N. Van der Noot, A. J. Ijspeert, and R. Ronsse, "Biped Gait Controller for Large Speed Variations, Combining Reflexes and a Central Pattern Generator in a Neuromuscular Model", in *2015 IEEE International Conference on Robotics and Automation*, 26-30 May 2015.

N. Van der Noot, L. Colasanto, A. Barrea ,J. van den Kieboom, R. Ronsse and A. J. Ijspeert , "Experimental Validation of a Bio-Inspired Controller for Dynamic Walking with a Humanoid Robot", in *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 28 September-02 October 2015.