Porting Reflex-Based Muscles Control to Real Humanoid Robots

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I. MOTIVATION

Dynamic locomotion control with humanoid robots can be achieved using many approaches. Among them, the ones relying on the zero-moment point (ZMP) are likely the most famous [1]. However, they present some drawbacks like energy-inefficiency and non human-like gait features: constant knee flexion (to avoid singularities), low waist position and feet kept parallel to the ground. Other problems usually encountered on many humanoid robots locomotion include limited walking speeds, high computational cost (especially for inverse dynamics-based controllers) and poor resistance against unstructured environments.

In parallel, bio-inspired approaches are being developed, taking inspiration from the more energy-efficient and robust features of real human gaits. One of them, developed by Geyer and Herr [2] generates locomotion by using Hill-type musculo-skeletal models driven by reflexes.

This approach is summarized in Fig. 1. Seven virtual muscles are identified within each leg. For each muscle, a neural input, called stimulation, is computed using reflex rules (see Fig. 1, right panel). These stimulations (further converted to activation signals) control the muscles contraction, and so the forces applied by the muscles on the body segments. Finally, all these forces are converted into torques, computed from the free-body diagram of each segment.

Interestingly, this approach solves most of the above-mentioned problems. However, this was only studied in simulation on a simplified seven-segments model. Our purpose is to port such bio-inspired controllers to a real humanoid robot, namely the COMAN [3], visible in Fig. 2.

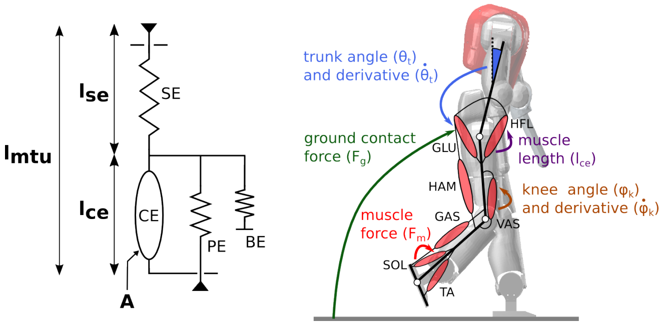


Fig. 1: Hill-type muscle with corresponding lengths and activation signal *A* (left panel). Robot depicted with the seven muscles of the right leg, together with some examples of stimulations driving these muscles (right panel).

II. CHALLENGES

Implementing this controller on a real robot involves many challenges compared to simulation studies: (i) working on real robotic devices requires to cope with the world non-idealities like friction forces or inaccurate torque tracking, (ii) the experimental procedure is heavier, more difficult to automate and more likely to damage the robot, (iii) an intensive optimization phase is required, which can hardly be performed on the real robot and (iv) the controller of [2] only addresses the problem of 2D walking, i.e no lateral balance is ensured.

Our strategy is then to first develop the controller in a simulation environment, with the purpose to minimize the reality-gap (accurate ground contact model, motor equations implemented, noise added on the sensors measurement…). Extensive optimization runs can then be performed in simulation to tune the controller unknown parameters. Once the controller achieves nice walking gaits in simulation, it can be ported to the real robot.

Regarding 2D walking, lateral stability is ensured in simulation by constraining the waist of the robot to stay in the world sagittal plane, see Fig. 2. This is not straightforward to get on the real robot. In our experiments, a human operator holds the robot by its wrists during walking motion. Then, the upper-body controller is specifically designed to provide lateral stability, while letting the robot move freely in the sagittal plane. This barely affects the lower-body control, which is actuating the leg sagittal joints (see Fig. 2), as described in [2].

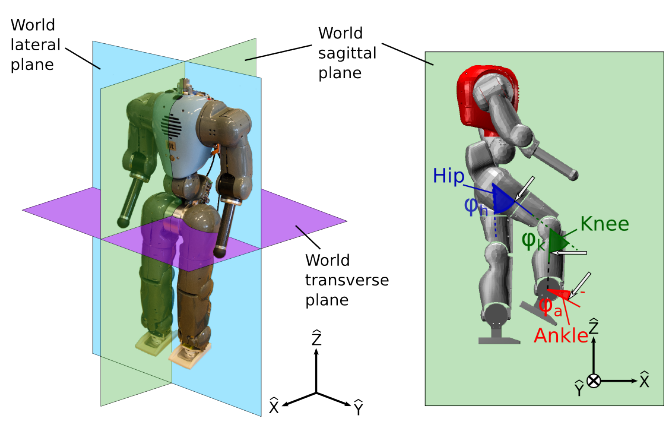
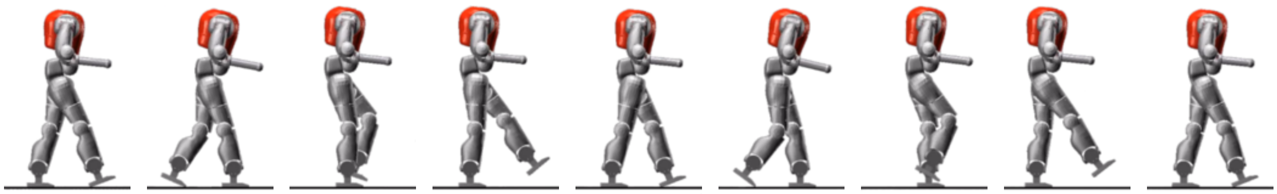
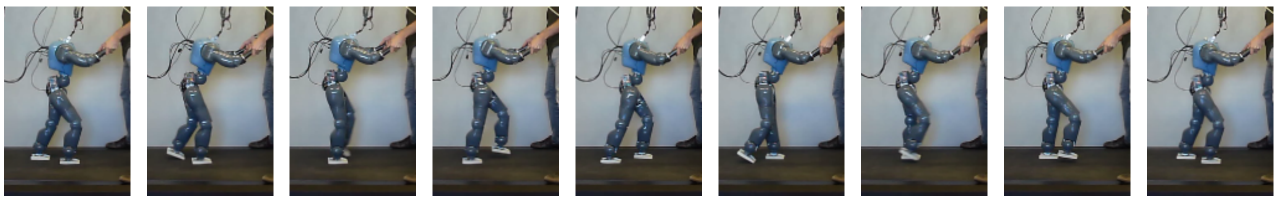


Fig. 2: The COMAN robot is presented along with the world planes (left panel). Forward locomotion is mainly achieved with the three leg sagittal joints: hip, knee and ankle (right panel).



(a) t=0 s (b) t=0.2 s (c) t=0.4 s (d) t=0.57 s (e) t=0.73 s (f) t=0.97 s (g) t=1.13 s (h) t=1.33 s (i) t=1.46 s

Fig. 3: COMAN walking in the simulation environment, after the optimization process. Snapshots (a), (e) and (i) are taken at foot strike, (b) and (f) at foot push-off, (c) and (g) when feet are adjacent and (d) and (h) during late swing.



(a) t=0 s (b) t=0.37 s (c) t=0.57 s (d) t=0.8 s (e) t=1.03 s (f) t=1.37 s (g) t=1.6 s (h) t=1.8 s (i) t=2.03 s

Fig. 4: Real COMAN walking on a treadmill with the exact same controller as in Fig. 3. These snapshots are consistent with the ones detailed in Fig. 3 (e.g. panel (a) is also taken at foot strike).

III. RESULTS

The gait obtained from simulations after the optimization process is displayed in Fig. 3. Running the exact same optimized controller on the real COMAN led to the gait presented in Fig. 4. The robot is walking on a treadmill while a human operator is grabbing its wrists (see section II) to provide lateral stability. This is a bit similar to an adult helping a child learning to walk.

Comparing these two gaits, we see that the stance leg behaviour is quite similar. In particular, the stance leg is fully stretched (see snapshots (d) and (h)), a feature usually absent in most robotic gaits (mainly due to singularity avoidance strategies). Early swing is also quite similar in both cases (see snapshots (b) and (f)), with rolling feet.

However, late swing exhibits some differences, mainly due to the non-stretching leg on the real robot. This is mainly due the high friction effects in the knee joints, which are not modelled in simulation. Consequently, this results in smaller steps. Moreover, a non-stretched swing leg requires more time to impact the ground, thus reducing the step frequency. These two combined effects lead to a smaller walking speed. Interestingly, if the swing leg was stretched, this would also cause the heel to strike before the toes, like on real humans.

Despite this significant difference between the optimized simulation gait and the one obtained on the real robot, COMAN still managed to walk. This demonstrates some kind of robustness of these bio-inspired controllers.

IV. PERSPECTIVES

These results call for further developments. A first one would be to extend the controller in order to solve the knee flexion issue. This would generate gaits being closer to the one optimized in simulation, so with higher speed, lower cost of transport and heel strikes. Moreover, it would be closer to real human gaits.

Another possible development is to extend the control rules to include lateral balance, and so to achieve 3D walking. Finally, we would like to test other bio-inspired controllers. In [4], we added feed-forward control rules, using oscillators to drive the muscles. This allows to modulate the the steps length and frequency, and so the walking speed (see Fig. 5).

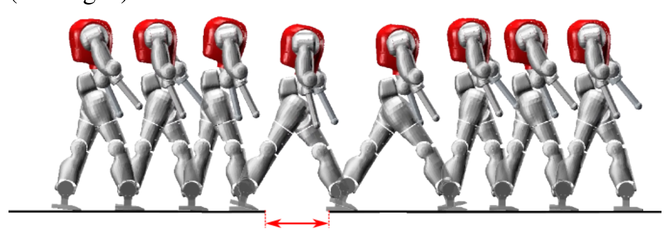


Fig. 5: Step length is modified to cross a hole.

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