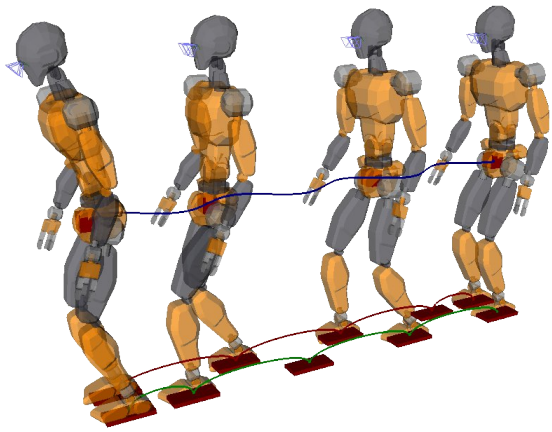
Robotics MVA 2025–26 Final exam topics

Model predictive control for bipedal locomotion

Context: Model predictive control (MPC) was historically one of the first successful applications of optimal control to robot locomotion. It was used to generate center-of-mass trajectories in an open-loop fashion ("walking pattern generation"), which were then executed on a real robot with the addition of a proper feedback controller ("stabilization"). Today model predictive control is directly used in closed loop (performing both walking pattern generation and stabilization in a single step) and with larger models than a point-mass (for instance a lumped rigid body), but the core ideas from center-of-mass MPC are still alive and well.



Goals: In this topic, we will start from the seminal MPC formulation as a quadratic program (QP) on a linear reduced model, and connect it to a visualization of our humanoid robot.

Project plan:

1. Read reference [1] below.
    a. Is it entirely correct? List what you find.
2. Reproduce the formulation and resolution of such a QP problem in Python with the library of your choice.
    a. You can use qpsolvers package to solve quadratic programs.
    b. Some tips and code snippets in this tutorial. Note that the *pymanoid* library mentioned in this tutorial has been discontinued, so you will need to adapt anything you see there to Pinocchio and your own knowledge.
3. Visualize the resulting COM trajectories (with the COM represented as a sphere moving in 3D) in the framework of your choice.
    a. *Bonus (optional) step***:** Visualize the robot tracking the trajectory as well, as in the above figure.
        i. You can use the Pink package to load a robot model in Pinocchio, make it track the COM target, and visualize it.
    b. MeshCat is a convenient visualizer used in robotics, ready-to-use with Pinocchio.
4. Choose one of the following extensions:
    a. **Extension F:** external forces are applied to the robot and the MPC should recompute footsteps accordingly.
        i. Check out reference [2].

ii. How much external force can it sustain, and with respect to which relevant parameters?

b. **Extension R:** the robot wants to track a circular rather than linear path. How can we do this?
   i. Hint: Constrain the ZMP to a small square inside the intersection of footstep areas with various orientations.
   ii. Check out references [2] and [3].
   iii. What is the minimum radius of curvature it can track, and with respect to which relevant parameters?

References:

- [1] Pierre-Brice Wieber. Trajectory Free Linear Model Predictive Control for Stable Walking in the Presence of Strong Perturbations. IEEE-RAS International Conference on Humanoid Robots, 2006, Genova, Italy.
- [2] Andrei Herdt, Holger Diedam, Pierre-Brice Wieber, Dimitar Dimitrov, Katja Mombaur, et al. Online Walking Motion Generation with Automatic Foot Step Placement. Advanced Robotics, 2010, Special Issue: Section Focused on Cutting Edge of Robotics in Japan 2010, 24 (5-6), pp.719-737.
- [3] Scianca, Nicola, et al. MPC for humanoid gait generation: Stability and feasibility. IEEE Transactions on Robotics 36.4 (2020): 1171-1188.