Humanoid controller for walking and jumping motions based on mc_rtc framework

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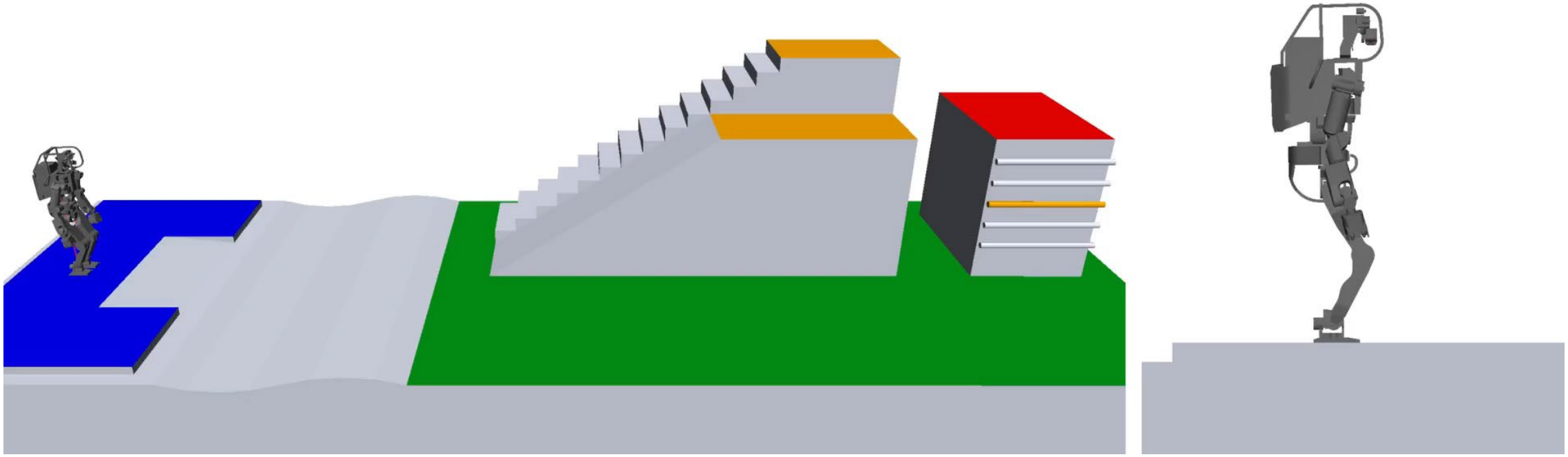
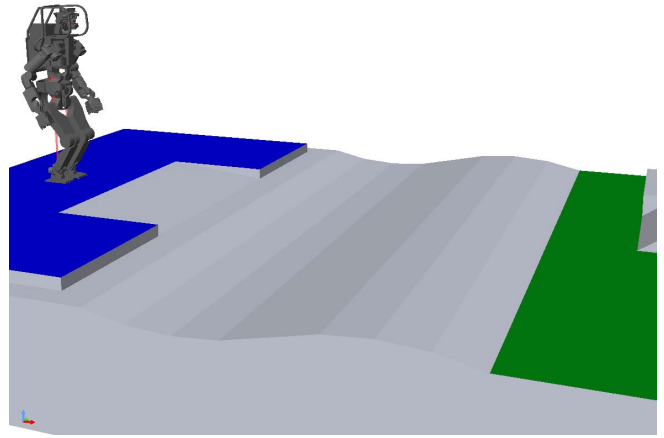
HVAC 2021 Results

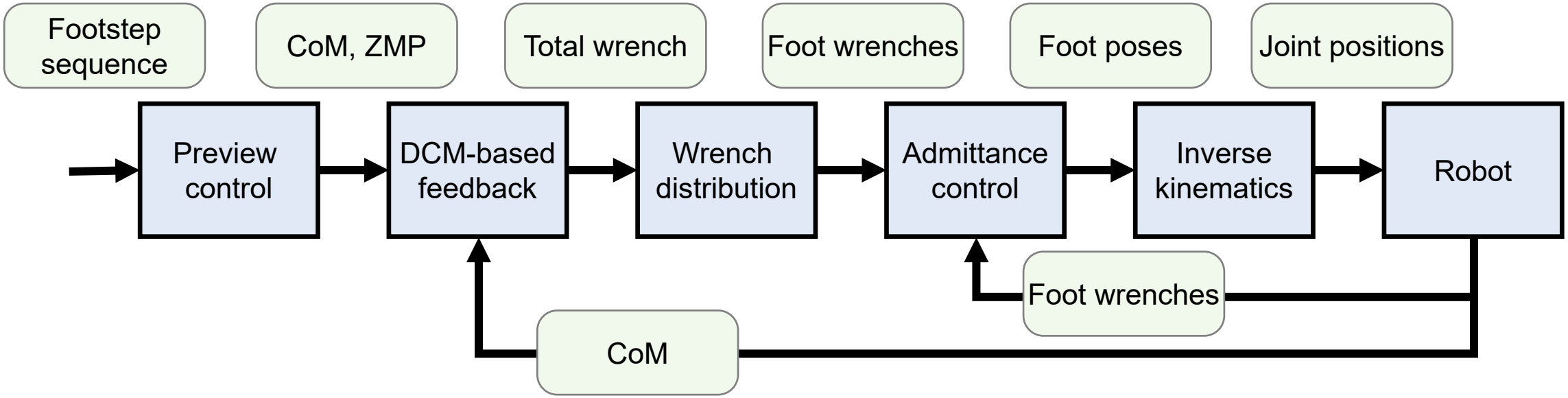


HRP-5P is walking on uneven ground, stairs, and jumping over gaps

Walking Control Method

- Integration of existing typical components



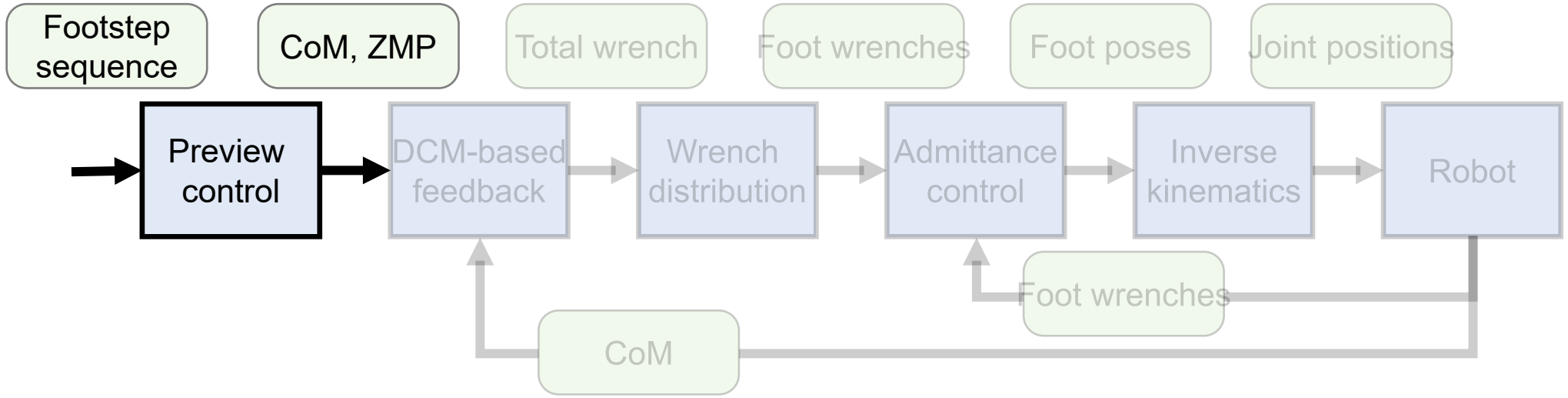


Preview Control

- Preview control provides closed-form solutions to the following problem [Kajita, ICRA'03]

$$\min_{\dddot{CoM}} \sum_{0}^{\infty} \| ZMP - ZMP^{ref} \|^2 + \| \dddot{CoM} \|^2 \quad \text{s.t.} \quad LIPM\ dynamics$$

- ZMP^{ref} is determined from a predefined footstep sequence
- Integrating the optimal $\dddot{CoM}$ yields the CoM^{plan} and ZMP^{plan}



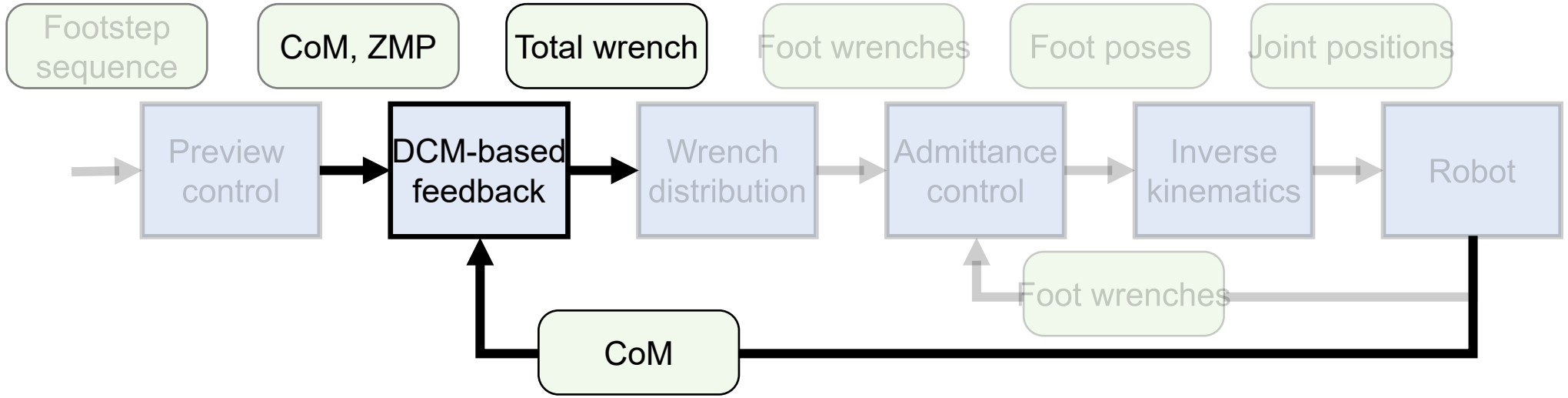
DCM-based feedback

- Modify ZMP to reduce errors due to disturbances

$$ZMP^{target} = ZMP^{plan} + K\left(DCM^{actual} - DCM^{plan}\right) \quad \text{where} \quad DCM = CoM + \dot{CoM}/\omega$$

- The optimal ratio of CoM and $\dot{CoM}$ feedback gains leads to DCM [Sugihara, ICRA'09]
- Convert target ZMP to total wrench

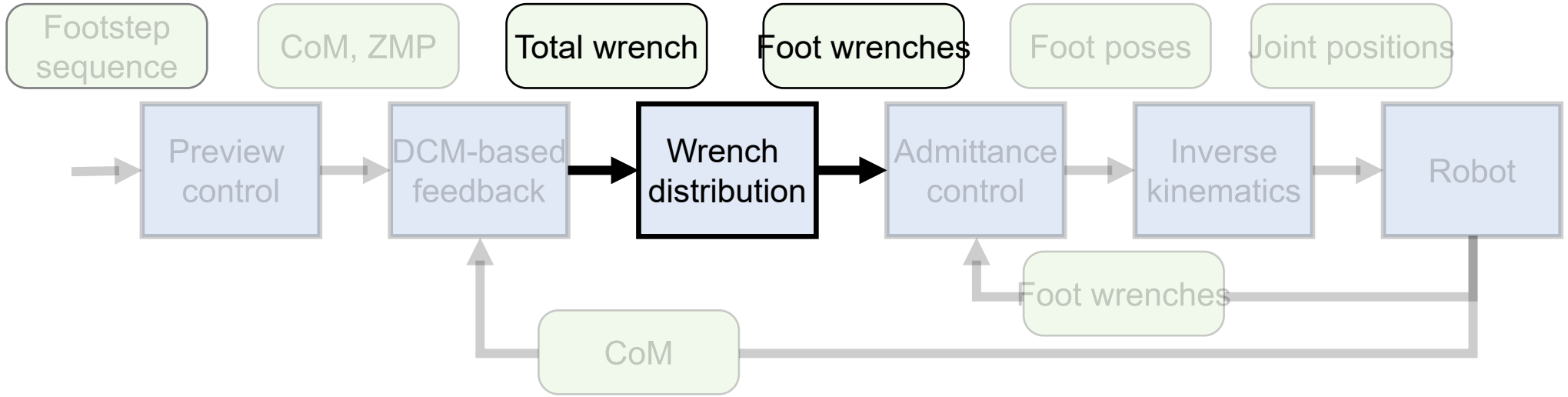
$$Force^{total} = m\,\omega^2(\,CoM - ZMP^{target}\,)$$



Wrench Distribution to Feet

- Distribute total wrench to each foot under friction constraints
- Formulated as a quadratic programming problem

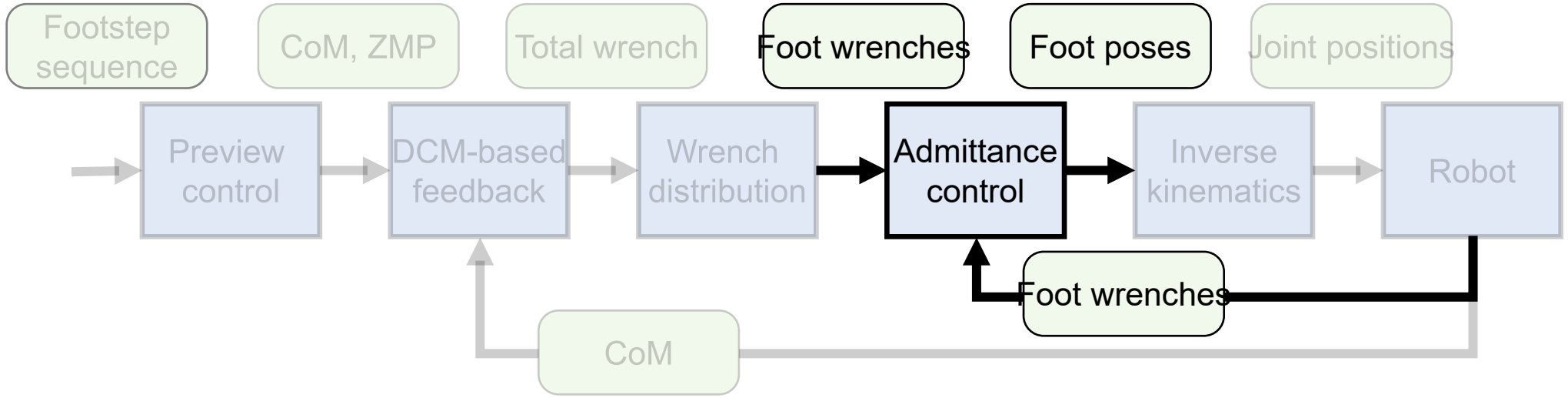
$$\min_{Wrehch^{foot}} \left\| Wrench^{total} - \sum_{foot} Wrench^{foot} \right\|^2 \quad \text{s.t.} \quad Wrench^{foot} \in Friction\,constraint$$



Foot Admittance Control

- Modify the foot pose to track target foot wrench

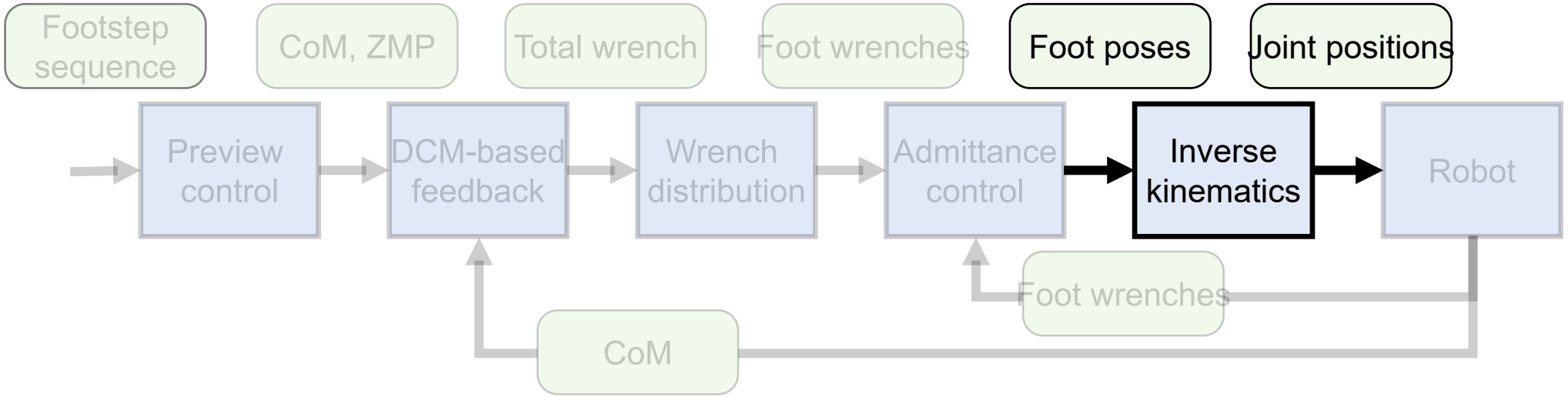
$$Pose^{target} \leftarrow Pose^{target} + \Delta Pose \quad \text{where} \quad \Delta Pose = D\,(Wrench^{actual} - Wrench^{target})$$



Inverse Kinematics

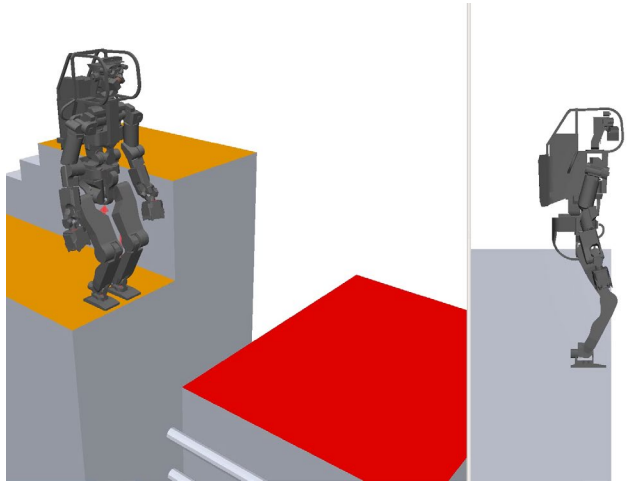
- Calculate joint positions that satisfy target CoM and foot poses
- Formulated as a quadratic programming problem

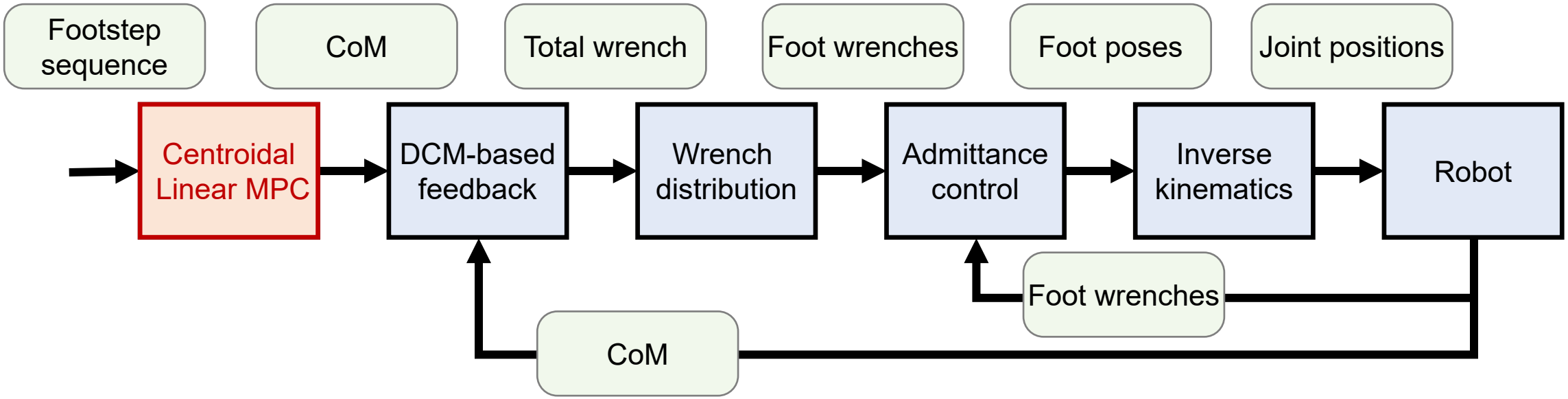
$$\theta \leftarrow \theta + \Delta\theta^* \quad \text{where} \quad \Delta\theta^* = \underset{\Delta\theta}{\operatorname{argmin}} \sum_{task} \left\| J_{task}\Delta\theta - \left(v_{task}^{target} - v_{task}^{current}\right)\right\|^2$$



Jumping Control Method

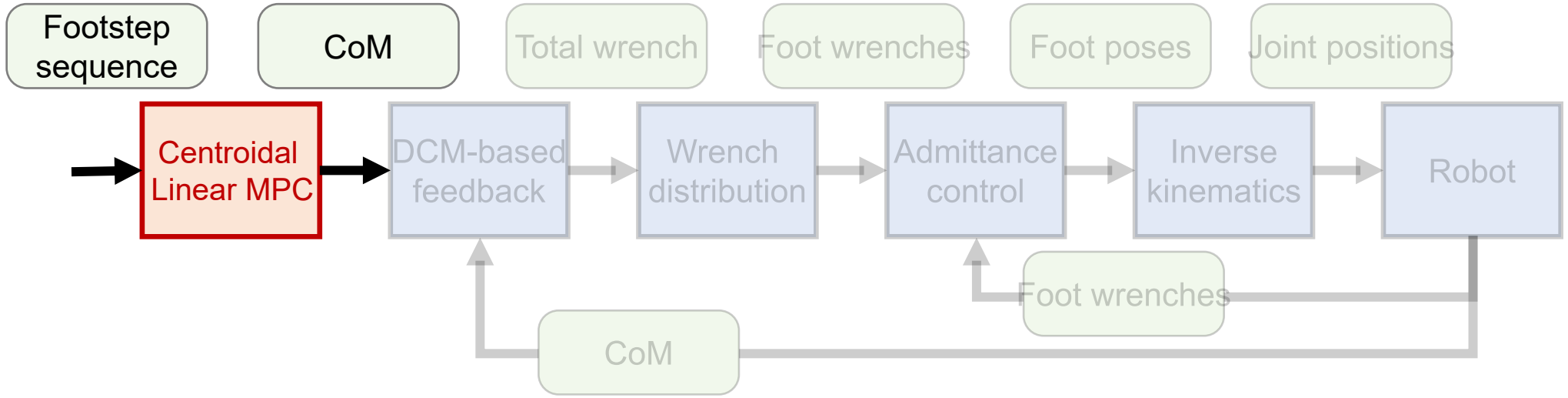
- The only difference from the walking control is the CoM planning
- Apply linear MPC based on centroidal dynamics





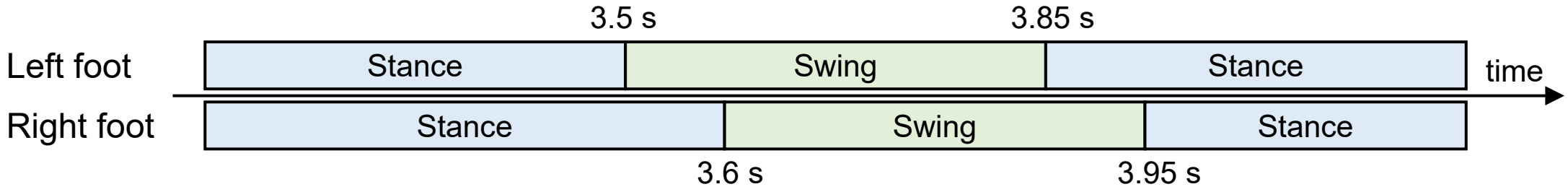
Centroidal Linear MPC

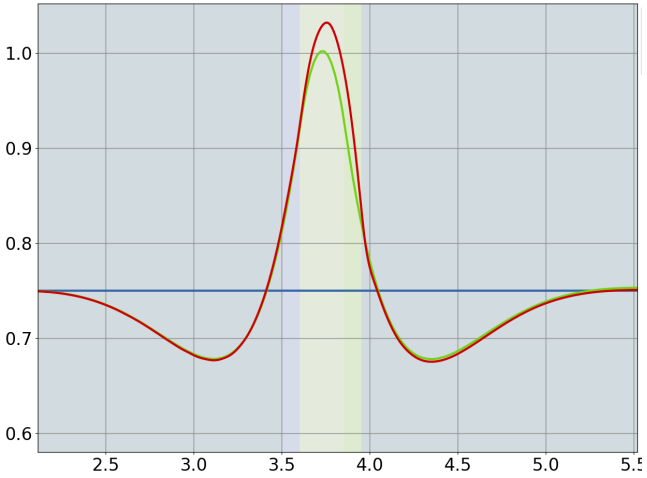
- Since centroidal dynamics is nonlinear, linear MPC cannot be applied as is
- Plan CoM vertical motion only (linear dynamics) with MPC
- Plan full centroidal motion (linear dynamics with known vertical motion) with MPC
  [Nagasaka, RoboSym'12 (in Japanese), Audren, IROS'14]
- Linear MPC is formulated as quadratic programming problem



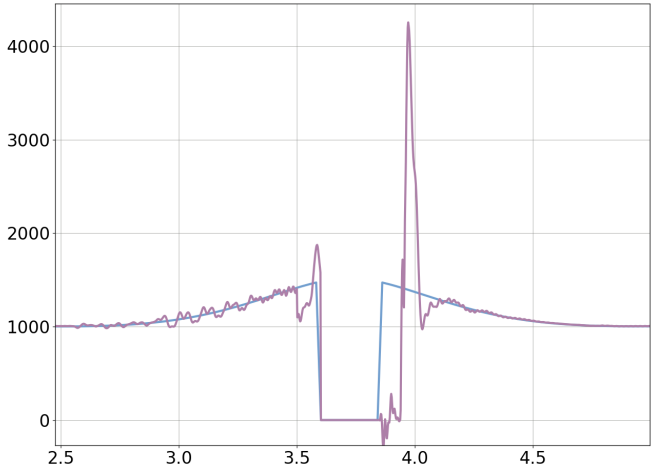
Centroidal Linear MPC

- Landing 1.4m forward with a jump of 0.25 s floating phase
- Allow up to 4 times the limits for velocity and torque at knee and hip pitch joints

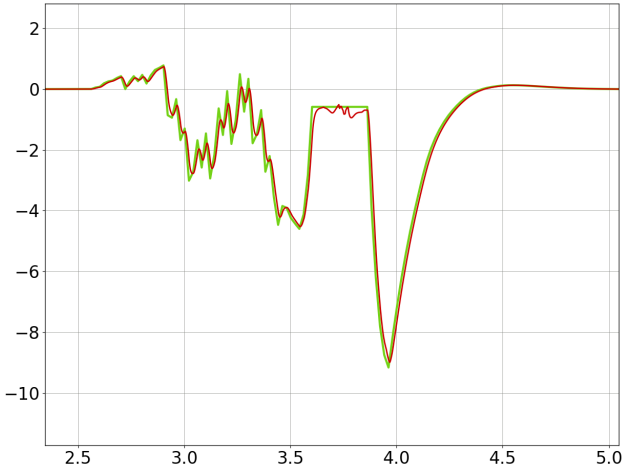




Vertical motion



Vertical force

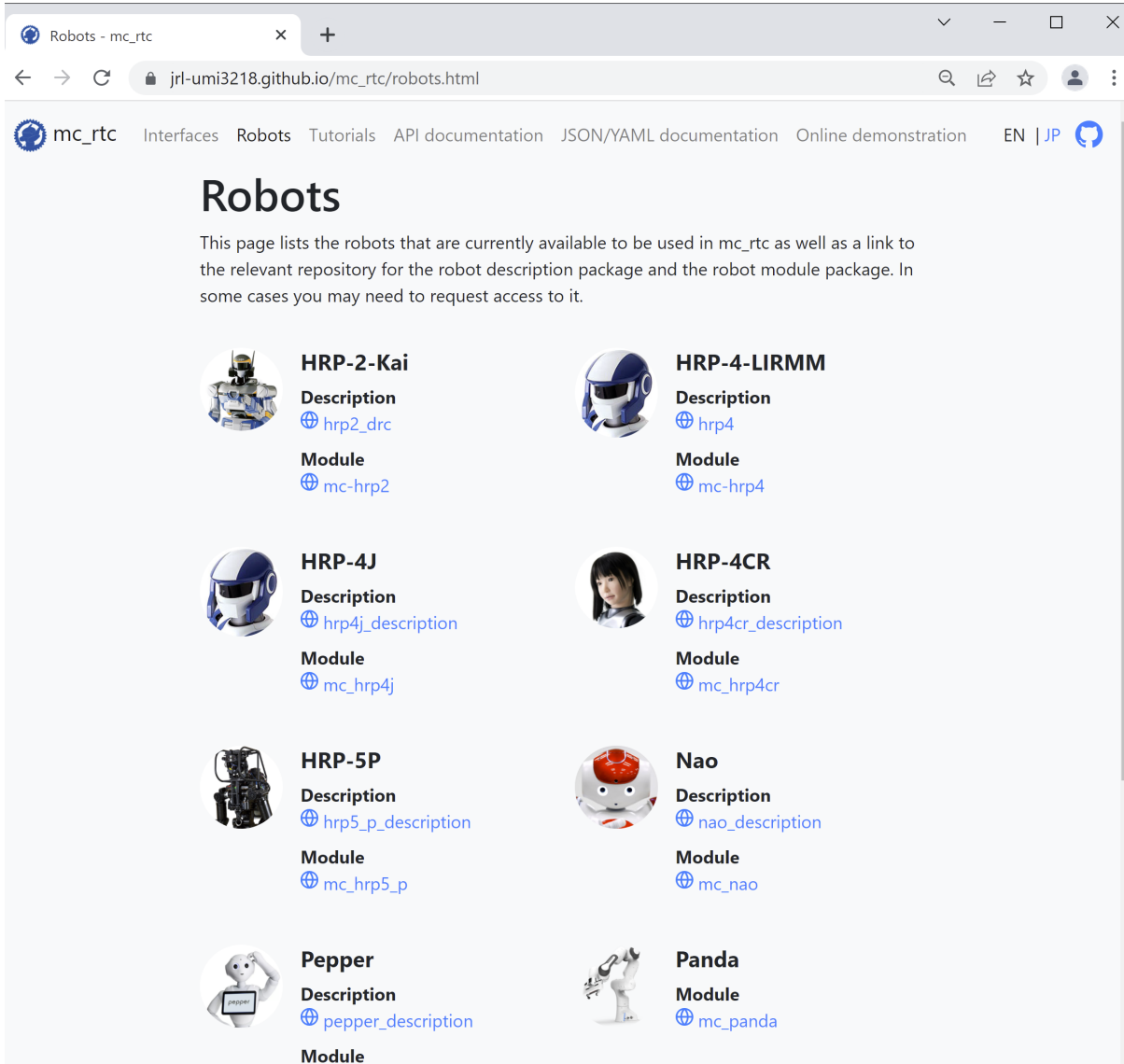


Pitch angular momentum

Control Framework mc_rtc

https://jrl-umi3218.github.io/mc_rtc/

- CNRS-AIST JRL develops mc_rtc
  - Kinematics and dynamics algorithms
  - Robot modeling
  - Logging and utility functions
  - Documentation
  - CI environments



Tutorial at Humanoids 2022
mc_rtc: An Application Framework for Robotics
November 28th, 2022. Room B3

Open-source Walking Controller BaselineWalkingController

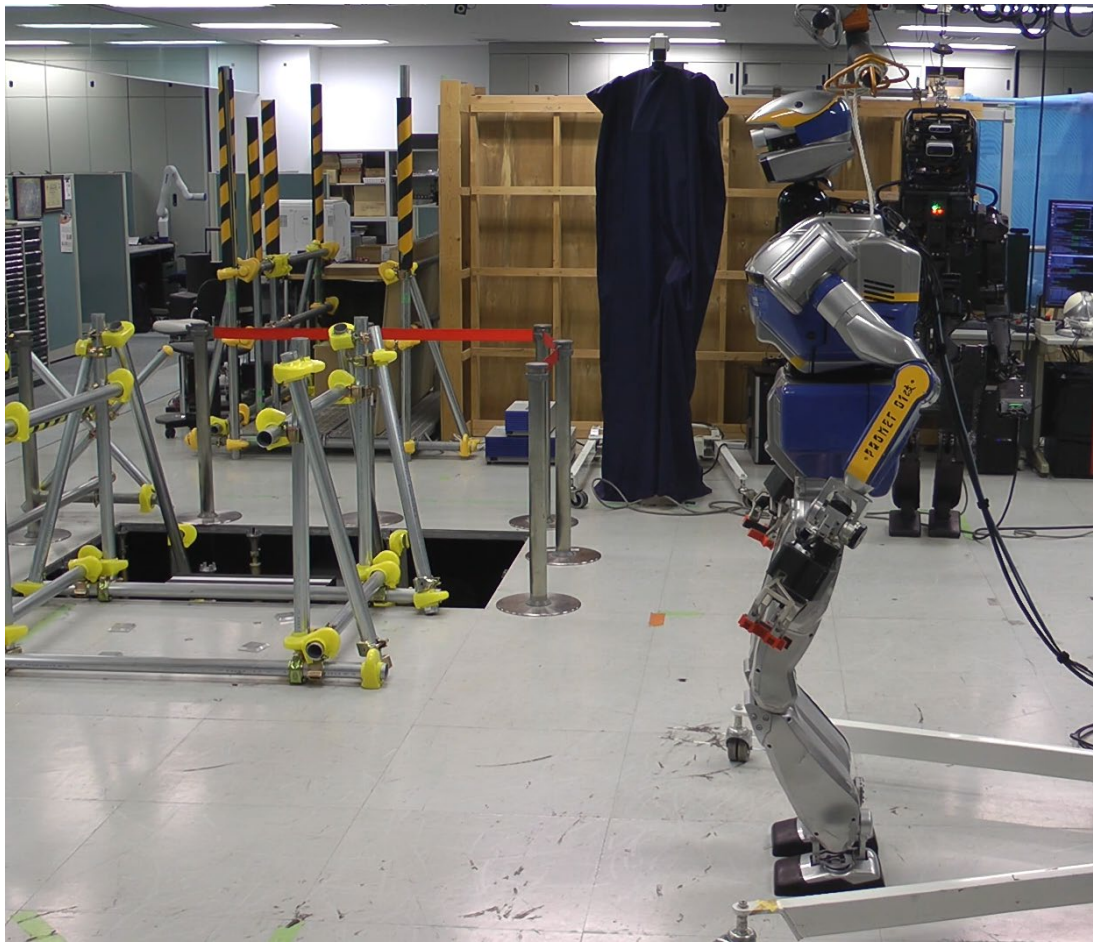
- ✓ Tested on real robots
- ✓ Dynamics simulation tests is run on CI environments
- ✓ Docker image is released with the latest version of the controller
- ✓ Easy to switch between various methods for CoM planning
- ✓ Easy to switch between “closed-loop MPC” and “open-loop MPC + stabilizer”

isri-aist / BaselineWalkingController Public

https://github.com/isri-aist/BaselineWalkingController

Real Robot Testing of BaselineWalkingController

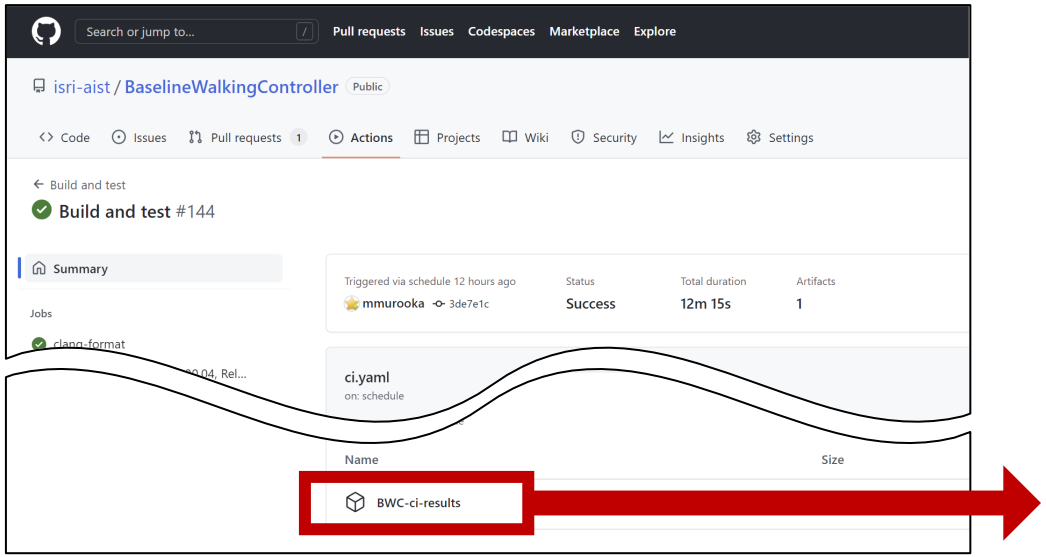
HRP-5P (Test on Nov.11th)

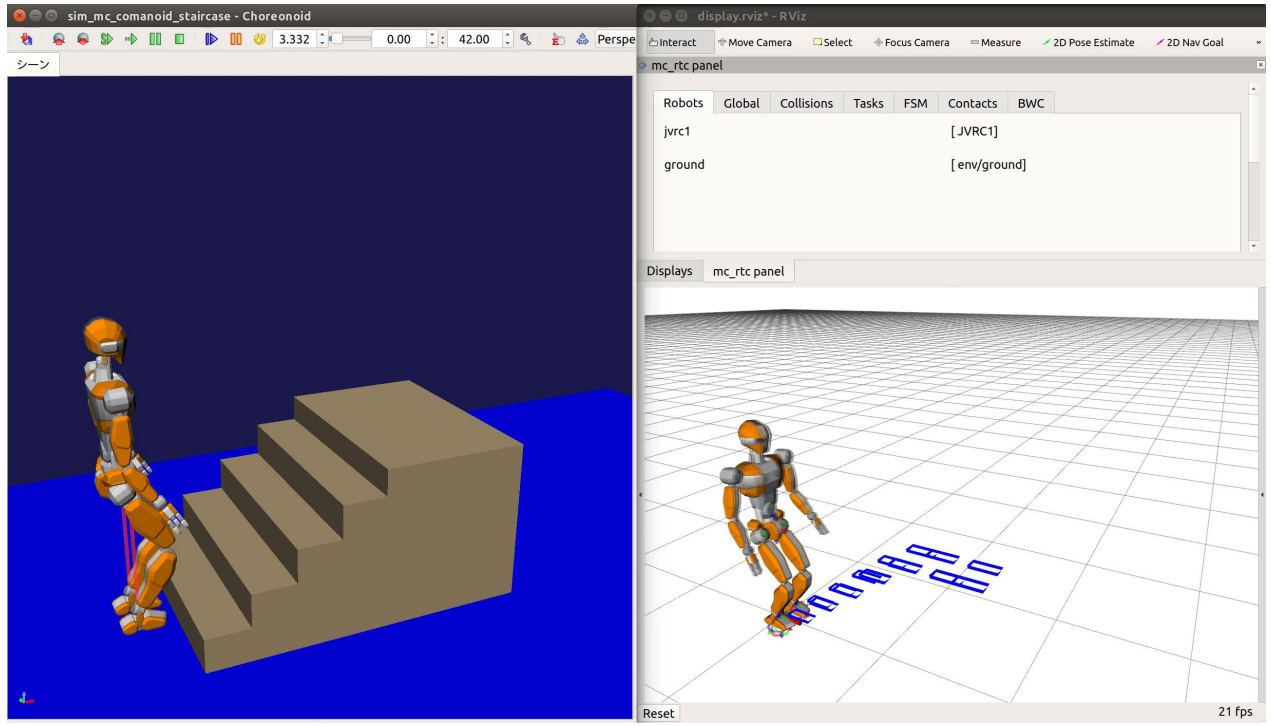


HRP-2KAI (Test on Nov. 7th)

Simulation Tests on CI environments

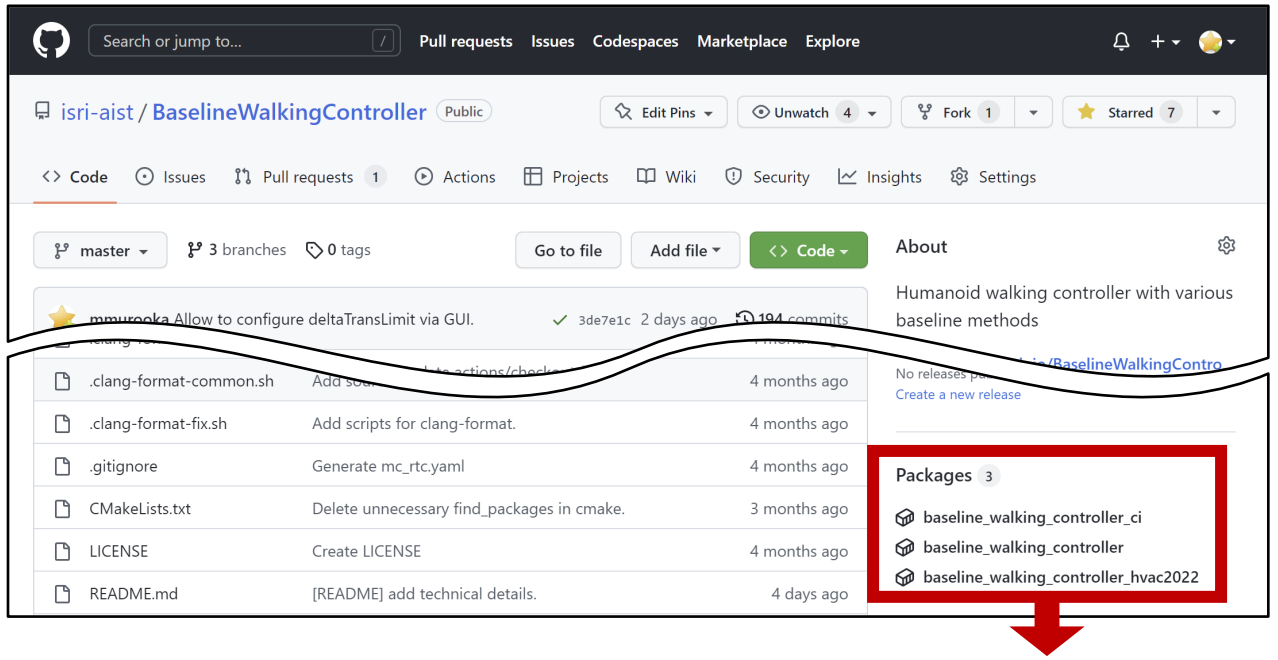
- Choreonoid tests are performed with every update on CI (GitHub Actions)





Automatic Release of Docker Images

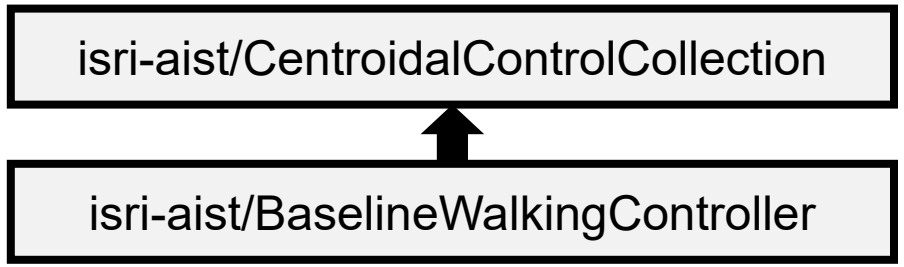
- Docker images are released on CI for every update




```
$ docker pull ghcr.io/isri-aist/baseline_walking_controller:latest
$ docker run --gpus all --rm -it
    --env="DISPLAY" –volume="/tmp/.X11-unix:/tmp/.X11-unix:rw"
    ghcr.io/isri-aist/baseline_walking_controller:latest ./walk_on_stairs.bash
```

Easy switching of CoM planning methods

- You can try the various CoM trajectory generation methods implemented in CentroidalControlCollection

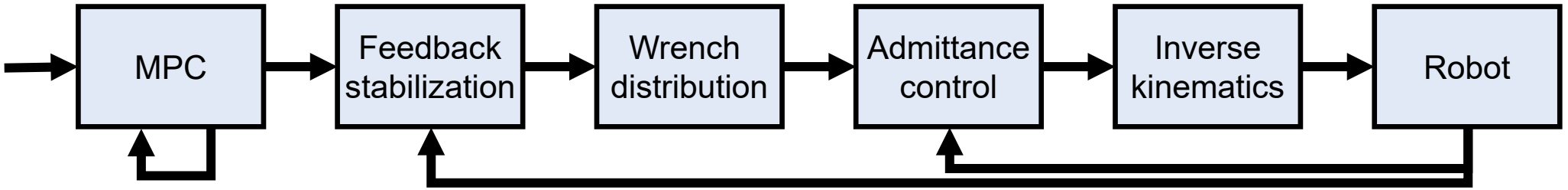


- List of methods
  - PreviewControlZmp [Kajita, ICRA'03]
  - DdpZmp [Feng, Journal of field robotics '15]
  - DcmTracking [Englsberger, IROS'13]
  - FootGuidedControl [Sugihara, IROS'17, Kojio, IROS'19]
  - LinearMpcZmp [Wieber, Humanoids'06]
  - IntrinsicallyStableMpc [Scianca, Humanoids'16]
  - SingularPreviewControlZmp [Urata, Humanoids'11]

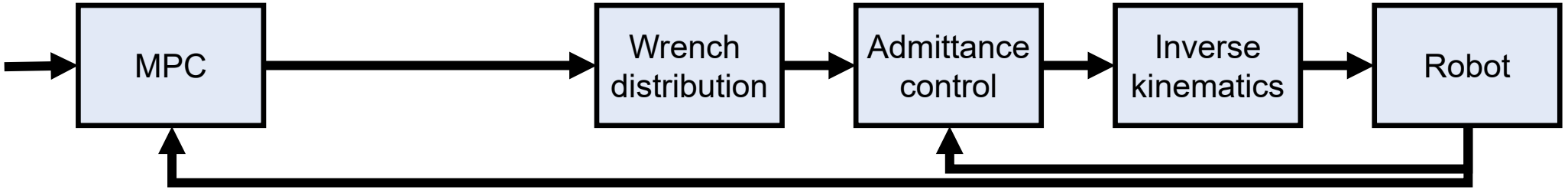
Easy switching of open/closed-loop MPC

- Open-loop MPC is often used implicitly in bipedal walking
- Differences between the two MPC schemes have not been fully discussed

Open-loop MPC + Feedback stabilization



Closed-loop MPC



Concluding remarks

- For beginners (and experts, of course), it is very helpful to be able to refer to a set of formulas in a paper and source code
- Let's share them in open discussion forums such as Humanoid Virtual Athletics Challenge