Stair Climbing Stabilization of the HRP-4 Humanoid Robot using Whole-body Admittance Control

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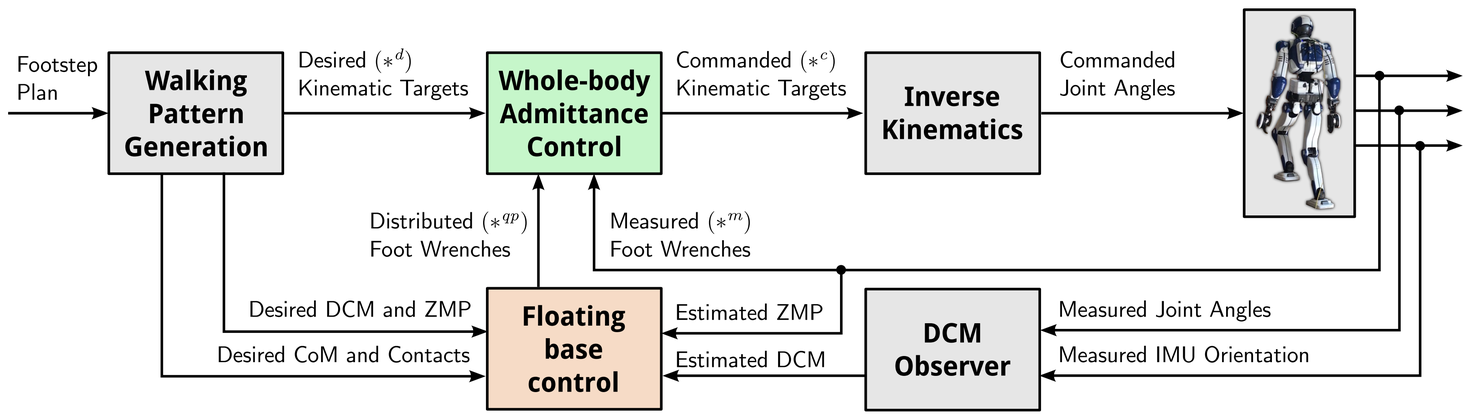
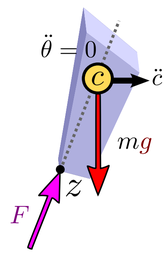
The floating base of mobile robots is **unactuated**: the only way to control it is by indirect force control.
Walking stabilization thus consists of two components: **floating base control** and **force control**.

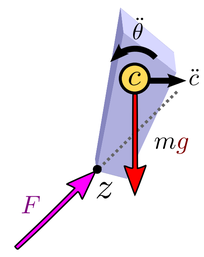
Floating base control

- Linear Inverted Pendulum Mode (LIPM):
  use subset of contact wrenches parameterized by ZMP
  $$\ddot{\boldsymbol{c}} = \omega^2(\boldsymbol{c} - \boldsymbol{z})$$
- Divergent Component of Motion (DCM):
  best coordinate to regulate floating base position
  $$\boldsymbol{\xi} = \boldsymbol{c} + \dot{\boldsymbol{c}}/\omega$$
- LIPM tracking by DCM feedback:
  $$\boldsymbol{z}^c = \boldsymbol{z}^d + K_{dcm}(\boldsymbol{\xi}^m - \boldsymbol{\xi}^d)$$
- Wrench distribution by Quadratic Programming

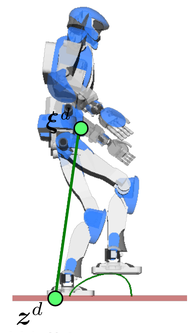




Net wrench is **LIPM**

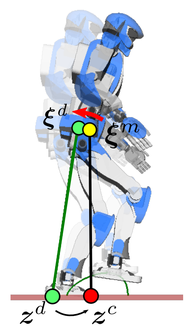


Net wrench is **not LIPM**



Walking pattern

No stabilizer



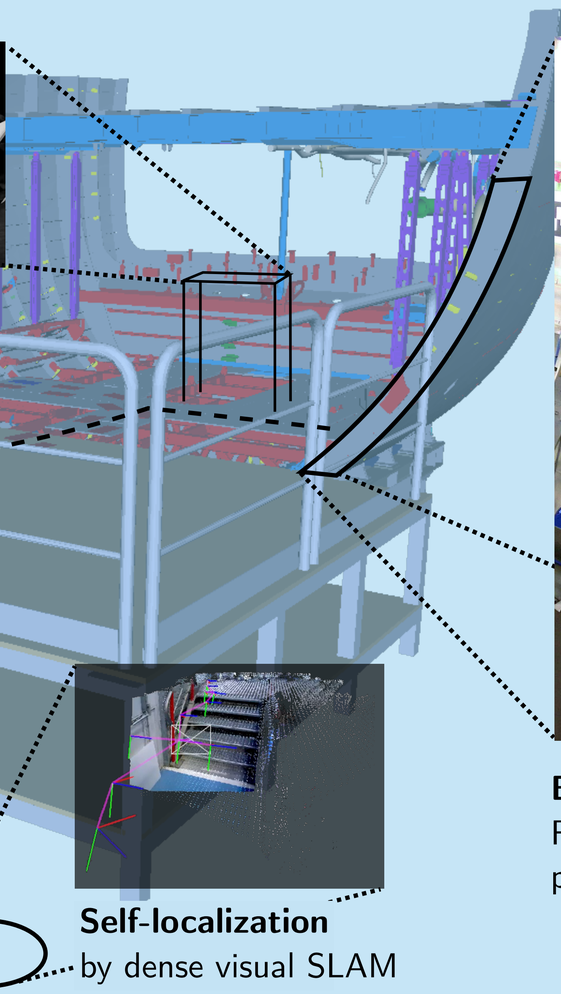
Effect of stabilizer

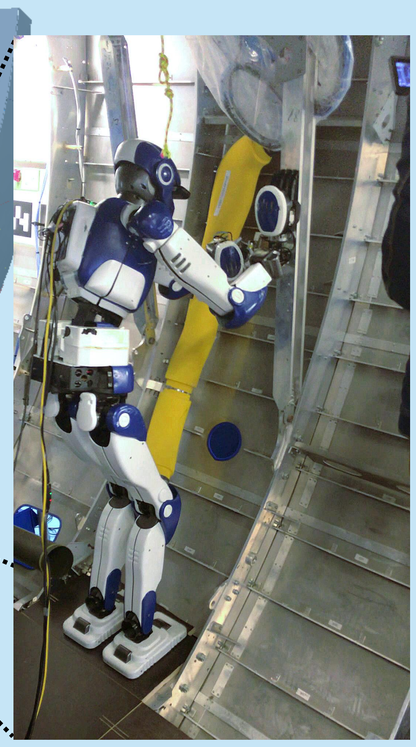
Humanoid in the aircraft factory

Demonstration run on-site
at the Airbus Saint-Nazaire factory
EU H2020 project COMANOID
(February 2019)

Industrial stair climbing
Step height is 18.5 cm

Bracket grasping
by visual servoing





Bracket fixturing use case
Robot leans in multi-contact posture for stabilization

Self-localization
by dense visual SLAM

Whole-body admittance control

Center of pressure control:
damping control on ankle flexibility

$$\dot{\theta} = \underbrace{A_{cop} f_z^m}_{\text{variable admittance}} \underbrace{(p_y^c - p_y^m)}_{\text{CoP error}}$$

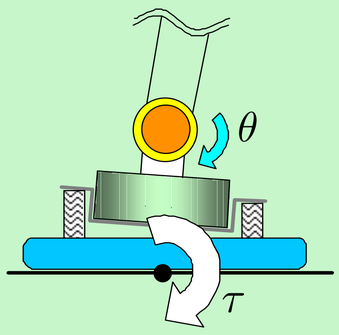


Figure adapted from Kajita *et al.* (2001)

End-effector task
Proposed in Kajita et al. (2010)

Foot force difference control:
change relative foot height during double support phases

$$\Delta f_z = f_{Lz} - f_{Rz}$$
$$\dot{z}_{ctrl} = A_{dfz}(\Delta f_z^c - \Delta f_z^m)$$

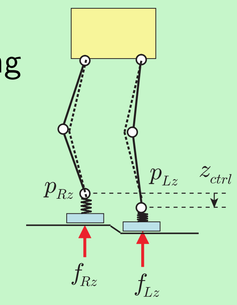
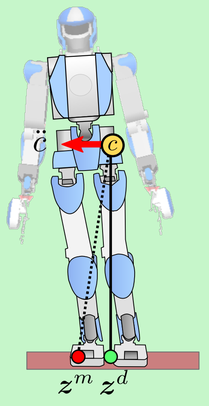


Figure adapted from Kajita *et al.* (2010)

Lower-body task
Proposed in Kajita *et al.* (2010)

CoM admittance control:
accelerate against the ZMP error

$$\ddot{\boldsymbol{c}} = \ddot{\boldsymbol{c}}^d + \boldsymbol{A}_{com}(\boldsymbol{z}^m - \boldsymbol{z}^c)$$
$$\boldsymbol{c} = \boldsymbol{c}^d + \iint(\ddot{\boldsymbol{c}} - \ddot{\boldsymbol{c}}^d)$$



Whole-body task
Proposed in Nagasaka (1996)

Combining all strategies **improves** the performance of force control for position-controlled robots.
However, too much compliance due to force control also degrades floating base position control...
How to achieve the best ratio between both?

https://github.com/stephane-caron/lipm_walking_controller/