# Planning and Executing Humanoid Gaits in a World of Stairs

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# Introduction

Abstract. Humanoid Robot Locomotion Problem.

# Block Scheme

- `elevation_mapping`: autonomously build a map $\mathcal{M}_z$
- RRT-based footstep planner: generate a footstep sequence $\{\boldsymbol{f}^j\}$ together with swing foot trajectories $\{\boldsymbol{p}^*_{\mathrm{swg}}\}$
- variable-height CoM IS-MPC: realize a stable trajectory $\boldsymbol{p}^*_{\mathrm{CoM}}$

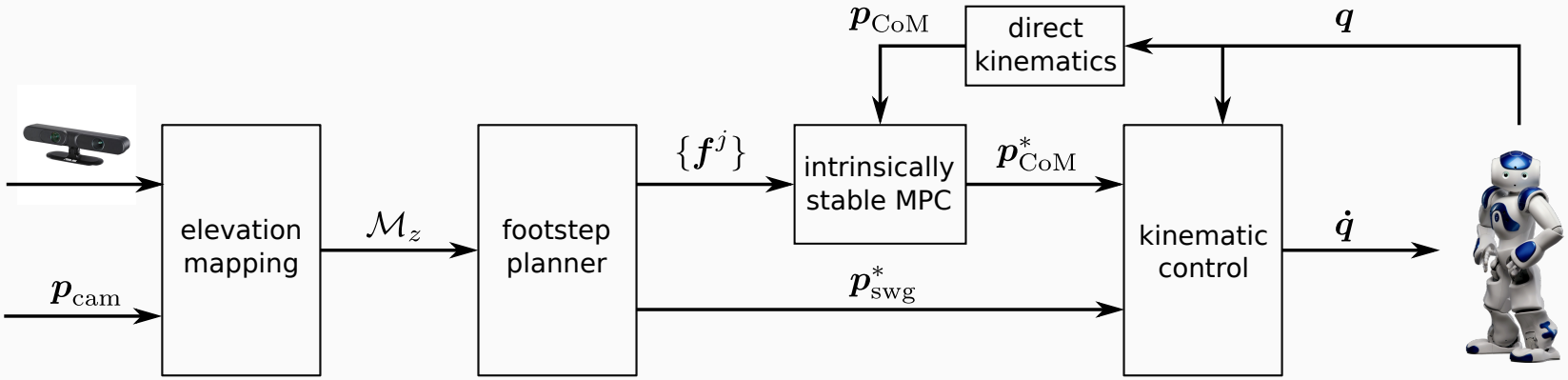


**Figure 1:** Block scheme of the approach.

# Variable Height CoM IS-MPC: 3D Motion Model

- LIP model not suitable for gait generation over uneven terrain
- constraint vertical motion such that

$$\frac{\ddot{z}_c + g}{z_c - z_z} = \omega^2$$

- CoM dynamics become

$$\ddot{x}_c = \omega^2(x_c - x_z)$$
$$\ddot{y}_c = \omega^2(y_c - y_z)$$
$$\ddot{z}_c = \omega^2(z_c - z_z) - g$$

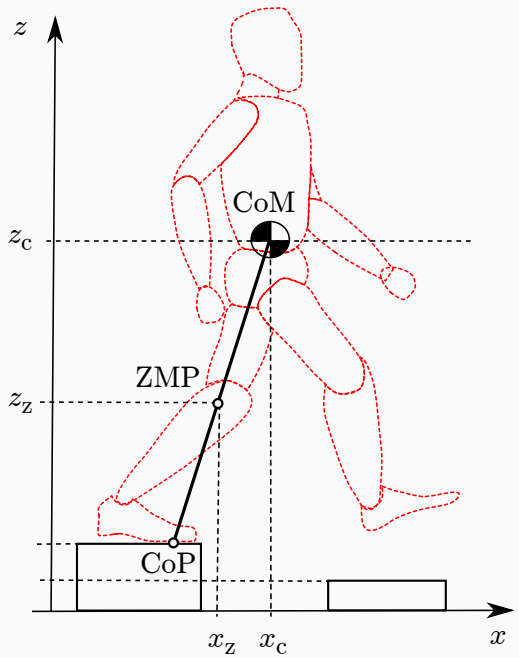


**Figure 2:** ZMP, CoP and COM are colinear.

# Variable Height CoM IS-MPC: MPC Formulation

- constrain ZMP into subregion of polyhedral cone (box)

$$R_{k+i}^T \begin{pmatrix} x_z^{k+i} - x_f^{k+i} \\ y_z^{k+i} - y_f^{k+i} \\ z_z^{k+i} - y_f^{k+i} \end{pmatrix} \leq \frac{1}{2} \begin{pmatrix} \tilde{d}_x^z \\ \tilde{d}_y^z \\ d_z^z \end{pmatrix}$$

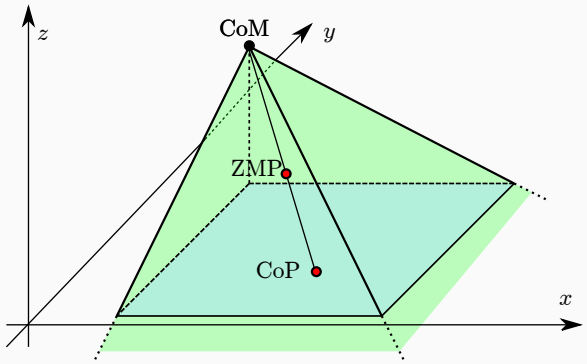


**Figure 3:** CoP internal to support polygon equivalent to ZMP internal to polyhedral cone.

- bound CoM wrt ZMP (LIP stability)

$$\frac{1}{\omega} \frac{1 - e^{-\delta\omega}}{1 - e^{-N\delta\omega}} \sum_{i=0}^{N-1} e^{-i\delta\omega} \dot{x}_z^{k+i} = x_c^k + \frac{\dot{x}_c^k}{\omega} - x_z^k$$

- solve QP problem using MPC scheme

# Variable Height CoM IS-MPC: Experiments

Experiments: Normal/Simple Staircase. Multiple Staircases (Up/Down).

# RRT-based Footstep Planning

Problem Formulation: R1, R2, R3. How the planner works (briefly). NAO's catalogue of primitives.

Experiment: Obstacle Avoidance.

# Elevation Map Generation

`elevation_mapping`, features, how it works (briefly). Settings: NAO + Xtion + *World of Stairs*.

Experiments: Generated Map + Stair Climbing in Unknown Environment.

Video

# Conclusion

Results. Future Works.

Q&A

# References


- A. Zamparelli, N. Scianca, L. Lanari, and G. Oriolo, "Humanoid Gait Generation on Uneven Ground using Intrinsically Stable MPC," *IFAC-PapersOnLine*, vol. 51, pp. 393–398, 01 2018.
- P. Ferrari, N. Scianca, L. Lanari, and G. Oriolo, "An integrated motion planner/controller for humanoid robots on uneven ground," in *18th European Control Conference, ECC 2019, Naples, Italy, June 25-28, 2019*, pp. 1598–1603, 2019.
- P. Fankhauser, M. Bloesch, and M. Hutter, "Probabilistic terrain mapping for mobile robots with uncertain localization," *IEEE Robotics and Automation Letters (RA-L)*, vol. 3, no. 4, pp. 3019–3026, 2018.