TUM Institute for Cognitive Systems (ICS)

OpenWalker

Module Description: Balancer (BM)

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1 Module Description

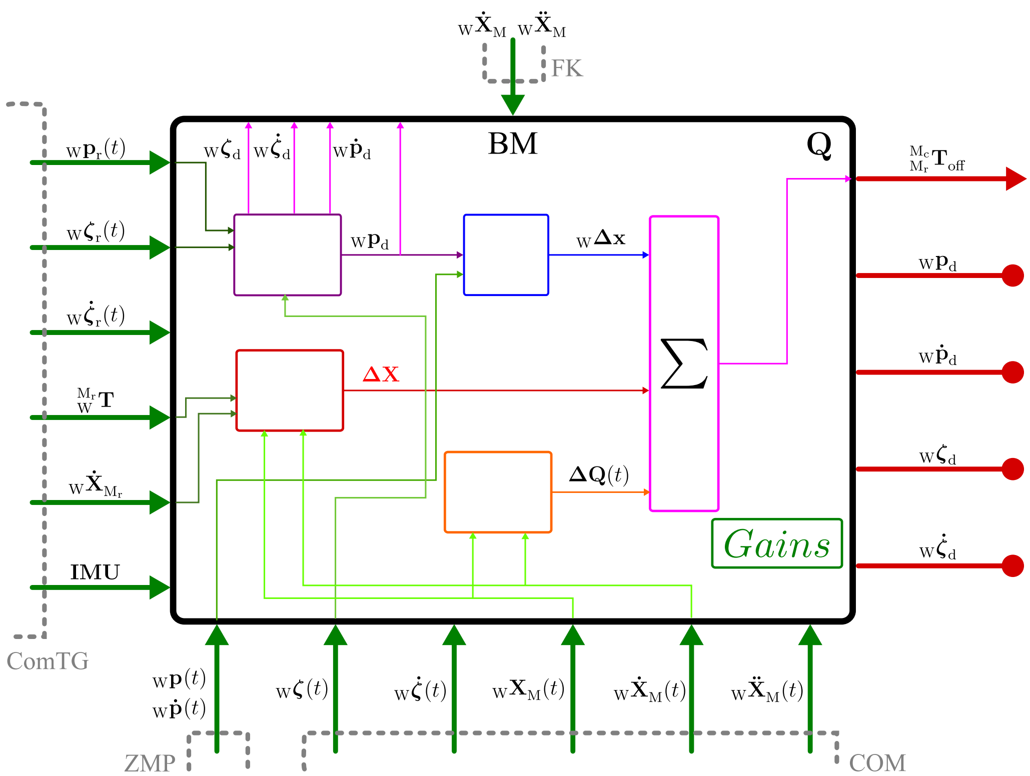

Figure 1.1: Balancer module: This module ensures the tracking of the reference CoM trajectory while suppressing external disturbances to keep both standing and walking balance.

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This module implements controllers to enforce the convergence of the real walking states (DCM, ZMP and CoM) to the reference trajectories. The desired states are computed from the reference trajectories in the form of continuous offset which are later added to the reference on the command generator module.

The module is composed by four controllers:

- **DCM tracker:** Computes a desired ZMP from the reference ZMP and the DCM error.
- **ZMP tracker:** Computes an offset to pull the CoM trajectory in order to track the desired ZMP with the real ZMP.
- **CoM Tracker:** Computes an offset to pull the commanded CoM trajectory to follow the reference CoM trajectory.
- **IMU orientation controller:** Computes a rotational offset fo correct the attitude of the base link to the reference orientation.

All the outputs of these controllers are then combined in an offset homogeneous transformation which will be used in the Command Generator module to compute the Command poses.

2 Module Connections

2.1 Inputs

Symbol	**Name**	**Type**	**Description**
${}_{\mathrm{W}}\mathbf{p}_{\mathrm{r}} \in \mathbb{R}^3$	Reference ZMP	`ZeroMomentPoint`	Reference trajectory for the ZMP.
${}_{\mathrm{W}}\boldsymbol{\zeta}_{\mathrm{r}} \in \mathbb{R}^3$	Reference DCM Position	`DivergentComponentOfMotion`	Reference trajectory for the DCM.
${}_{\mathrm{W}}\dot{\boldsymbol{\zeta}}_{\mathrm{r}} \in \mathbb{R}^3$	Reference DCM Velocity	`DivergentComponentOfMotion`	Derivative of the reference trajectory for the DCM.
${}^{\mathrm{M_r}}_{\mathrm{W}}\mathbf{T} \in \mathbb{R}^{4\times4}$	Reference CoM Position	`HomogeneousTransformation`	Reference trajectory for the CoM. This includes both position and orientation of a virtual link located at the CoM with the same oriantation of the base link.
${}_{\mathrm{W}}\dot{\mathbf{X}}_{\mathrm{M_r}} \in \mathbb{R}^6$	Reference CoM Velocity	`CartesianVelocity`	Derivative of the reference trajectory for the CoM. This includes both linear and angular velocities of the base link.
$\ddot{\mathbf{x}}_{\mathrm{imu}} \in \mathbb{R}^3$	IMU Linear Acceleration	`LinearAcceleration`	This vector contains the linear acceleration measured by the Inertial Measurement Unit (IMU) sensor of the robot.
$\mathbf{Q}_{\mathrm{imu}} \in \mathbb{R}^4$	IMU Angular Position	`AngularPosition`	This vector contains the angular position in quaternion measured by the Inertial Measurement Unit (IMU) sensor of the robot.
${}_{\mathrm{W}}\mathbf{p} \in \mathbb{R}^3$	Real ZMP	`ZeroMomentPoint`	Real ZMP with respect to the world.
${}_{\mathrm{W}}\dot{\mathbf{p}} \in \mathbb{R}^3$	Real ZMP velocity	`ZeroMomentPointP`	First derivative o real ZMP with respect to the world.
${}_{\in\mathbb{R}}\boldsymbol{\zeta}_{\mathrm{W}}3$	Real DCM with respect to the world.	`DivergentComponentOfMotion`	Real position of the DCM with respect to the world.
${}_{\mathrm{W}}\dot{\boldsymbol{\zeta}} \in \mathbb{R}^3$	Reference DCM Velocity	`DivergentComponentOfMotionP`	Derivative of the real DCM with respect to the world.
${}^{\mathrm{M}}_{\mathrm{W}}\mathbf{T} \in \mathbb{R}^{4\times4}$	Real CoM Position	`HomogeneousTransformation`	Real position of the CoM. This includes both position and orientation of a virtual link located at the CoM with the same oriantation of the base link.
${}_{\mathrm{W}}\dot{\mathbf{X}}_{\mathrm{M}} \in \mathbb{R}^6$	Real CoM Velocity	`CartesianVelocity`	Derivative of the real trajectory of the CoM. This includes both linear and angular velocities of the base link.

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2.2 Outputs

Symbol	Name	Type	Description
${}^{\mathrm{CoM_{cmd}}}_{\mathrm{CoM_r}}\mathbf{T}_{\mathrm{off}} \in \mathbb{R}^{4\times 4}$	COM offset	`HomogeneousTransformation`	Offset needed on the COM commanded position to keep balance and track the reference trajectories with the real position.
${}_{\mathrm{W}}\boldsymbol{\zeta}_{\mathrm{d}} \in \mathbb{R}^3$	Desired DCM Position	`DivergentComponentOfMotion`	Adjusted trajectory for the DCM to keep balance.
${}_{\mathrm{W}}\dot{\boldsymbol{\zeta}}_{\mathrm{d}} \in \mathbb{R}^3$	Desired DCM Velocity	`DivergentComponentOfMotionP`	Adjusted velocity for the DCM to keep balance.
${}_{\mathrm{W}}\mathbf{p}_{\mathrm{d}} \in \mathbb{R}^3$	Desired ZMP	`ZeroMomentPoint`	Adjusted trajectory for the ZMP to keep balance and track the desired DCM.

2.3 Inter-Connections

This module receives all the reference trajectories and their derivatives from the CoM trajectory generator module (CoMTG), the IMU sensor data form the Real Robot module (RR), the real ZMP and its derivative from the ZMP module, and all the output from the real CoM module. The output of this module is connected to the Command generator module which combines the offsets with the reference trajectories.

2.4 Common Methods

There are several techniques for biped balance control as shown in [1]. One simple method to stabilize the LIPM model is to define a a proportional ZMP and CoM tracker in the form

$$ {}_{\mathrm{W}}\dot{\mathbf{x}}_{\mathrm{M_d}} = k_{\mathrm{zmp}}\left({}_{\mathrm{W}}\mathbf{p} - {}_{\mathrm{W}}\mathbf{x}_{\mathrm{M}}\right) + k_{\mathrm{M}}\left({}_{\mathrm{W}}\mathbf{x}_{\mathrm{M_r}} - {}_{\mathrm{W}}\mathbf{x}_{\mathrm{M}}\right) \tag{2.1} $$

where $k_{\mathrm{zmp}}, k_{\mathrm{M}} \in \mathbb{R}$ are positive gains. Another method is to stabilize the LIPM using LQR-control which results in a control in the form

$$ {}_{\mathrm{W}}\dot{\mathbf{x}}_{\mathrm{M_d}} = -k_1\,{}_{\mathrm{W}}\mathbf{p} - k_2\,{}_{\mathrm{W}}\mathbf{x}_{\mathrm{M}} - k_3\,{}_{\mathrm{W}}\dot{\mathbf{x}}_{\mathrm{M_r}} \tag{2.2} $$

where $k_1, k_2, k_3 \in \mathbb{R}$ are optimal gains tunned with LQR.

Finally, one las example is to adjust the desired ZMP position for tracking the reference DCM as described in [2]

$$ {}_{\mathrm{W}}\mathbf{p}_{\mathrm{d}} = k_{\mathrm{d}}\,{}_{\mathrm{W}}\boldsymbol{\zeta}_{\mathrm{r}} - \left(k_{\mathrm{d}} - 1\right){}_{\mathrm{W}}\boldsymbol{\zeta} \tag{2.3} $$

with $k_{\mathrm{d}} < 0 \in \mathbb{R}$. This desired ZMP can the be tracked with a simple PD as

$$ {}_{\mathrm{W}}\dot{\mathbf{x}}_{\mathrm{M_d}} = k_{\mathrm{zmp}}\left({}_{\mathrm{W}}\mathbf{p} - {}_{\mathrm{W}}\mathbf{p}_{\mathrm{d}}\right) + k_{\mathrm{d}}\,{}_{\mathrm{W}}\dot{\mathbf{p}} \tag{2.4} $$

References

[1] Kajita, Shuuji, et al. Introduction to humanoid robotics. Vol. 101. Springer Berlin Heidelberg, 2014.

[2] Englsberger, Johannes, and Christian Ott. "Integration of vertical com motion and angular momentum in an extended capture point tracking controller for bipedal walking." 2012 12th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2012). IEEE, 2012..

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