TUM Institute for Cognitive Systems (ICS)

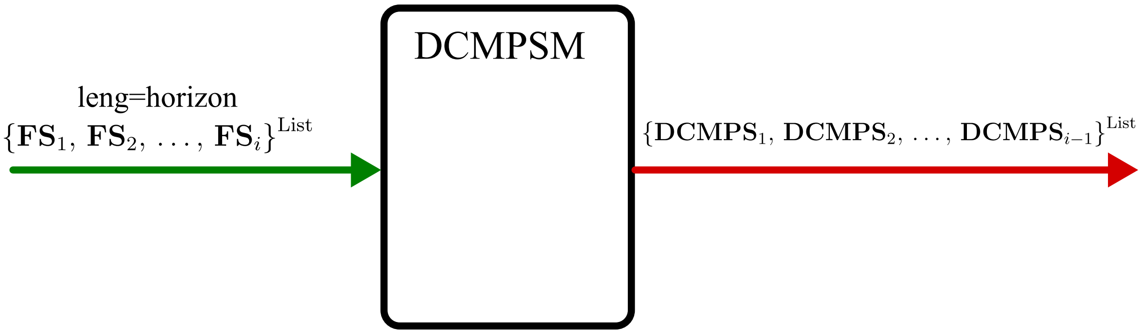
OpenWalker

Module Description: DCM Planner (DCMPSM)

Rogelio Guadarrama-Olvera, Emmanuel Dean, Florian Bergner,
Simon Armleder, and Gordon Cheng

February 14, 2020

1 Module Description



$$\mathbf{DCMPS} = \left[\mathbf{r}_i,\, \boldsymbol{\zeta}_i,\, \boldsymbol{\zeta}_{\text{DS, ini},\, i},\, \boldsymbol{\zeta}_{\text{DS, final},\, i},\, \dot{\boldsymbol{\zeta}}_{\text{DS, ini},\, i}\, \dot{\boldsymbol{\zeta}}_{\text{DS, final},\, i}\right]$$

Figure 1.1: DCM Planner module: This module generates a set of way points for the Divergent Component of Motion (also known as Capture Point) controller, from the planned footsteps.

This module receives the planned feasible footsteps and computes the way points for the Divergent Component of Motion (DCM) dynamics for a stable walking motion. These points describe the transitions between one footstep to the next for the DCM which define an attractor point for the Center of Mass dynamics using the Linear Inverted Pendulum Model. These points also include the initial and final point of the double support phase used to smooth discontinuities on the DCM trajectory.

The computed **DCM** points for the i-th step (**DCMPS**$_i$) are the Virtual Repellent Point $\mathbf{r}_i \in \mathbb{R}^3$, the step Capture Point $\boldsymbol{\zeta}_i \in \mathbb{R}^3$, the initial Capture Point for the double support phase

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 732287.

$\boldsymbol{\zeta}_{\mathrm{DS,ini},i} \in \mathbb{R}^3$, the final Capture Point for the double support phase $\boldsymbol{\zeta}_{\mathrm{DS,final},i} \in \mathbb{R}^3$, the initial Capture Point velocity for the double support phase $\dot{\boldsymbol{\zeta}}_{\mathrm{DS,ini},i} \in \mathbb{R}^3$, the final Capture Point velocity for the double support phase $\dot{\boldsymbol{\zeta}}_{\mathrm{DS,final},i} \in \mathbb{R}^3$.

This module must update the planned way points every time that the footstep plan is changed. However, the computation of these points is not very demanding for a reduced number of steps ahead. The algorithms to compute DCM way points require a minimum plan of 4 steps ahead of the current executed step.

2 Module Connections

2.1 Inputs

Symbol	**Name**	**Type**	**Description**
$\{\mathbf{FS}_i\}$	Footstep List	`FootStepList`	A list containing the planned footsteps, where $\mathbf{FS}_i = \left[\mathbf{X}_{\mathrm{FS},i},\, l_i,\, s_i,\, n_i\right]$ with $\mathbf{X}_{\mathrm{FS},i} = \left[\mathbf{x}_{\mathrm{FS},i},\, \mathbf{Q}_{\mathrm{FS},i}\right]$

2.2 Outputs

Symbol	**Name**	**Type**	**Description**
$\{\mathbf{DCMPS}_i\}$	DCM Point Set List	`DCMPointSet`	A list containing the DCM way points needed to execute the planned footsteps, where $\mathbf{DCMPS}_i = \left[\mathbf{r}_i,\, \boldsymbol{\zeta}_i,\, \boldsymbol{\zeta}_{\mathrm{DS,ini},i},\, \boldsymbol{\zeta}_{\mathrm{DS,final},i},\, \dot{\boldsymbol{\zeta}}_{\mathrm{DS,ini},i},\, \dot{\boldsymbol{\zeta}}_{\mathrm{DS,final},i}\right]$

2.3 Inter-Connections

This module receives the list of planned footsteps from the Footstep Planner (FSP) module. This port is shared with the Foot Trajectory Generator (FTG) module. The output of the DCMP module is connected to the CoM Trajectory Generator module.

2.4 Common Methods

There are different ways of generating stable walking motions. The most simple method considers an instantaneous double support phase and instantaneous foot transitions [1]. The process starts with a set of n foot locations from the footstep plan. Then, for the i-th foot location $\mathbf{x}_{\mathrm{FS},i}$, a virtual repellent point is defined as

$$\mathbf{r}_i = \mathbf{x}_{\mathrm{FS},i} + \begin{bmatrix} 0 & 0 & z_{\mathrm{M}} \end{bmatrix}^{\top} \tag{2.1}$$

where z_{M} is the defined height for the CoM. Then, the i-th way point for the DCM can be computed as

$$\boldsymbol{\zeta}_i = \mathbf{r}_{i+1} + \mathrm{e}^{-\omega t_{\mathrm{step}}} \left(\boldsymbol{\zeta}_{i+1} - \mathbf{r}_{i+1}\right) \tag{2.2}$$

$$\dot{\boldsymbol{\zeta}}_i = -\omega\, t_{\mathrm{step}}\, \mathrm{e}^{-\omega t_{\mathrm{step}}} \left(\boldsymbol{\zeta}_{i+1} - \mathbf{r}_{i+1}\right) \tag{2.3}$$

where $\omega = \sqrt{\frac{g}{z_{\mathrm{M}}}}$ is the natural frequency of the LIPM and t_{step} is the step time defined in the walking parameters.

The minor index in the left side of (2.3) than in the right side means that these points must be computed from the last footstep in the plan to the current step. This also requires that $\boldsymbol{\zeta}_n = \boldsymbol{r}_n$ (the last planned step).

The instantaneous foot transitions result in discontinuous DCM trajectories which produce high tangential ground reaction forces on the standing foot. This condition is prone to foot skidding. To reduce these effects, one strategy to smooth the DCM trajectories is to introduce a continuous transition in a double support phase [3]. To achieve this, an initial and final way point for the double supporting phase must be computed as

$$\begin{aligned}
\boldsymbol{\zeta}_{\mathrm{DS,ini},i} &= \mathbf{r}_{i-1} + \mathrm{e}^{-0.5\omega t_{\mathrm{DS}}}\left[\boldsymbol{\zeta}_i - \mathbf{r}_{i-1}\right] && (2.4)\\
\dot{\boldsymbol{\zeta}}_{\mathrm{DS,ini},i} &= -\omega\, t_{\mathrm{step}}\, \mathrm{e}^{-0.5\omega t_{\mathrm{DS}}}\left[\boldsymbol{\zeta}_i - \mathbf{r}_{i-1}\right] && (2.5)\\
\boldsymbol{\zeta}_{\mathrm{DS,final},i} &= \mathbf{r}_i + \mathrm{e}^{0.5\omega t_{\mathrm{DS}}}\left[\boldsymbol{\zeta}_i - \mathbf{r}_i\right] && (2.6)\\
\dot{\boldsymbol{\zeta}}_{\mathrm{DS,final},i} &= -\omega\, t_{\mathrm{step}}\, \mathrm{e}^{0.5\omega t_{\mathrm{DS}}}\left[\boldsymbol{\zeta}_i - \mathbf{r}_i\right] && (2.7)
\end{aligned}$$

where t_{DS} is the double support time defined in the walking parameters. A generalization of these methods for uneven terrain is described in [3].

References

[1] Englsberger, Johannes, et al. "Bipedal walking control based on capture point dynamics." 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE, 2011.

[2] Romualdi, Giulio, et al. "A benchmarking of DCM based architectures for position and velocity controlled walking of humanoid robots." 2018 IEEE-RAS 18th International Conference on Humanoid Robots (Humanoids). IEEE, 2018.

[3] Englsberger, Johannes, et al. "Three-dimensional bipedal walking control based on divergent component of motion." Ieee transactions on robotics 31.2 (2015): 355-368.