Online Learning of Sagittal Push Recovery for Bipedal Robots

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Gait Control Framework

- Online learning with a robot in the loop is a promising way to learn a balanced walking controller.
- A central pattern generator simplifies the learning setting to the learning of leg swing amplitudes A.
- Balance control has the task of maintaining balance while tracking the reference step size $\check{S}.$
- The balance control function is represented by a function



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approximator $\mathbf{A} = \mathbf{F}(\boldsymbol{\theta}, \boldsymbol{\dot{\theta}})$.

- The trunk angle θ_E and the error S_E with respect to the reference step size are used to train the Balance Control function at the end of each step.
- During walking, the function approximator is queried at a high frequency.

Online Learning of Foot Placement

The trunk inclination $\theta_{\rm E}$ at the end of the step indicates the state of balance. Using the **pendulum-cart model**, a **gradient function** computes a suggested modification of the step size based on the trunk inclination and the step size error at the end of the step.

 $\mathbf{G}(\mathbf{\theta}_{\mathbf{E}},\mathbf{S}_{\mathbf{E}}) = \mathbf{\theta}_{\mathbf{E}} + p_1 \tanh(p_2 \mathbf{S}_{\mathbf{E}})$

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Sense,

 $\mathbf{G}(\mathbf{\theta}_{\mathrm{E}},\mathbf{S}_{\mathrm{E}})$

A function approximator (LWPR) in the loop is updated at the end of every step with the step size modification gradient for all states that were encountered during the step.

 $\mathbf{F}(\boldsymbol{\theta}_{i}, \dot{\boldsymbol{\theta}}_{i}) = \mathbf{F}(\boldsymbol{\theta}_{i}, \dot{\boldsymbol{\theta}}_{i}) + \eta \mathbf{G}(\boldsymbol{\theta}_{E}, \mathbf{S}_{E}) \forall i \in \mathbf{I}$

The trained function approximator is queried during walking with a high frequency. It returns the **leg swing amplitude** for the central pattern generator.

Results

• Bipedal robot Copedo successfully learns to absorb a strong push from the back that otherwise forces the robot to fall.



• The push recovery controller is learned from the experience of only a few failed steps during falling after the first push.



[1] Marcell Missura, Sven Behnke, "Online Learning of Foot Placement for Bipedal Walking", *Humanoids 2014.* Acknowledgement: This work has been supported by grant BE 2556/6-1 of German Research Foundation (DFG).