Instability Detection and Disturbance Rejection for Bipedal Walking

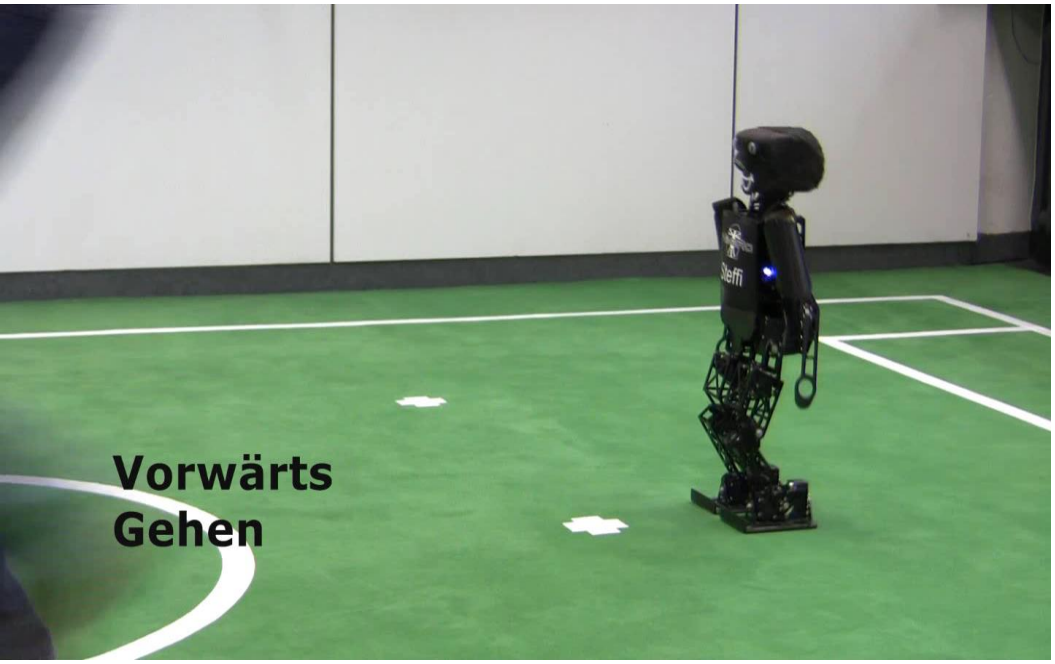
Sven Behnke

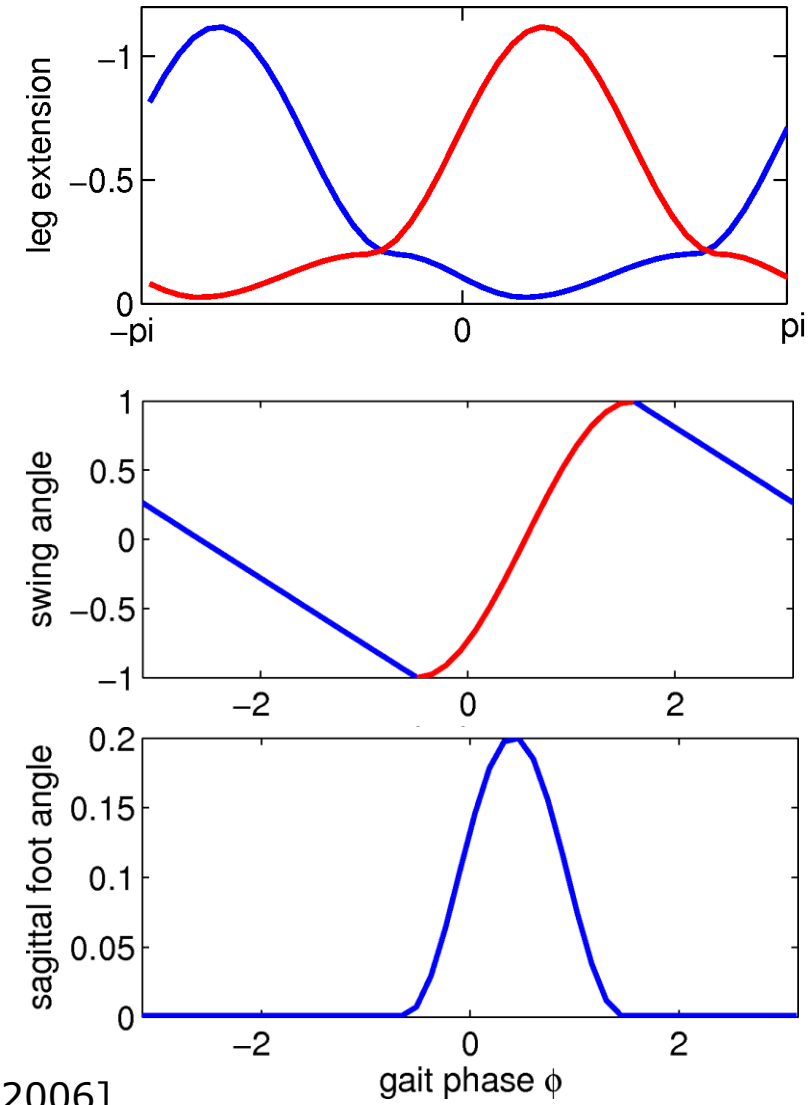
Autonomous Intelligent Systems

RoboCup 2008 KidSize Final
NimbRo vs. Team Osaka

Omnidirectional Walking

- Continuously changing walking speeds: sagittal, lateral, yaw
- Key ingredients:
  - Rhythmic weight shifting
  - Leg shortening
  - Swing in walking direction



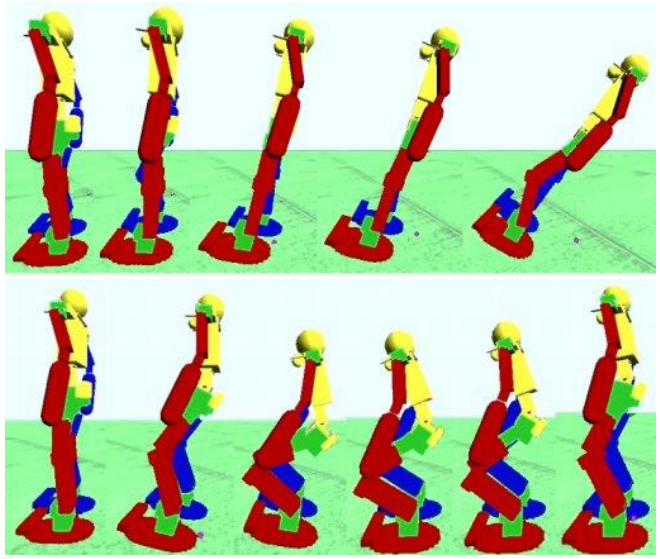


[Behnke: ICRA 2006]

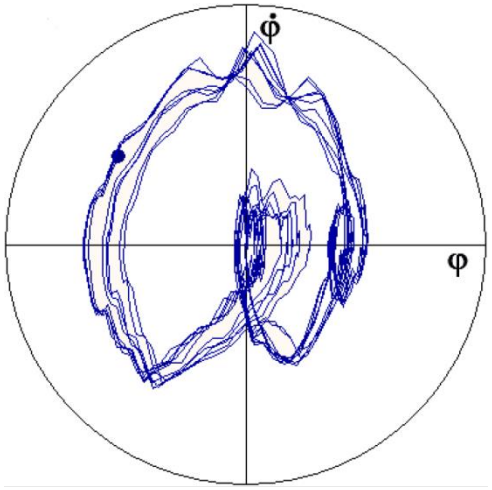
Fall Avoidance

[Renner, Behnke: IROS 2006]

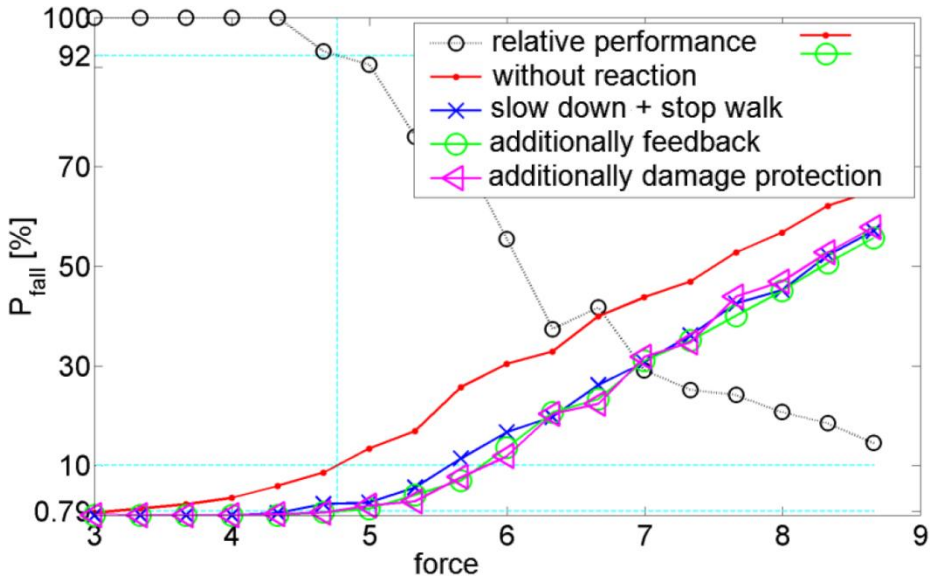
- Learn model of trunk attitude during undisturbed walking
- Aggregate deviations to instability measure
- Stabilizing reflexes
  - Slow down
  - Stop walking
  - Leap step



Lateral tilt



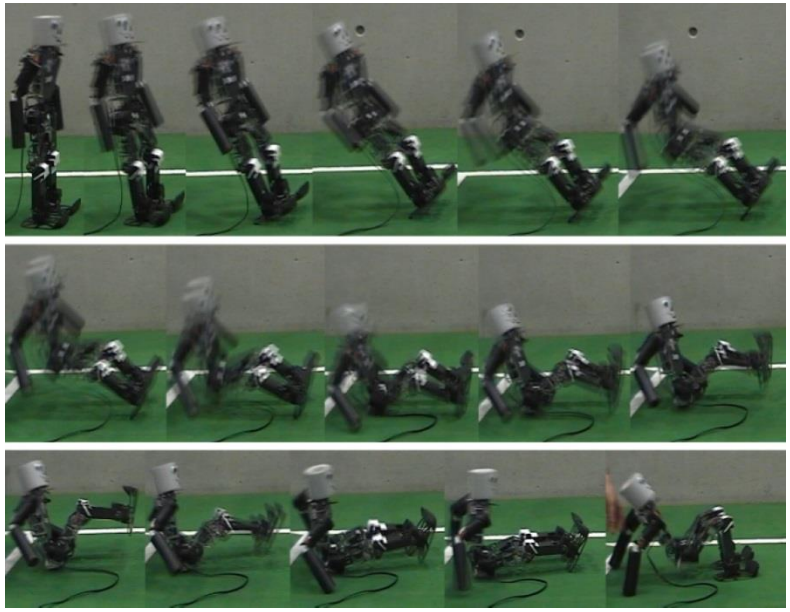
Results simulation

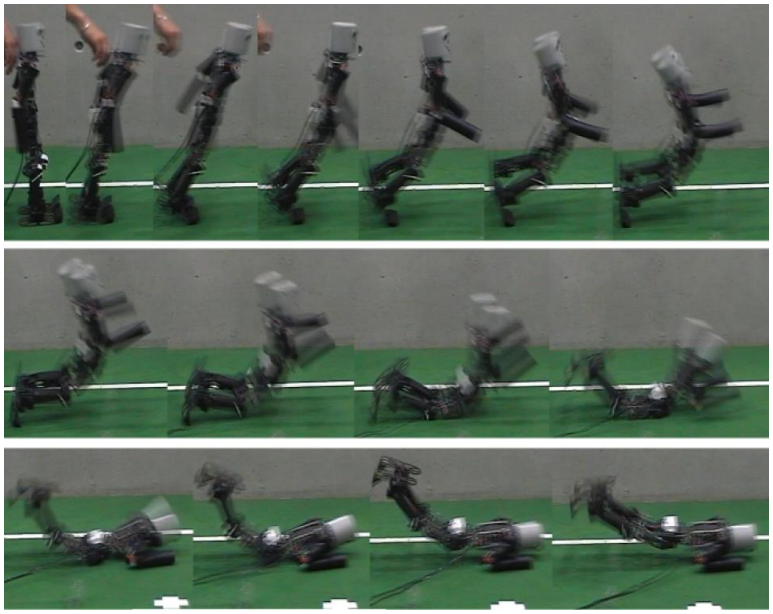


Controlled Fall

- Falls cannot be avoided completely
- Timely recognition by attitude estimation
- Landing at cushioned primary contact points
  - Knee (forward fall)
  - Lower back (backward fall)
- Arms as secondary contact points
- Relaxation of joints

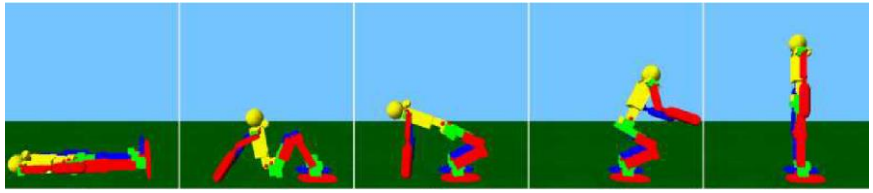
[Renner 2006]

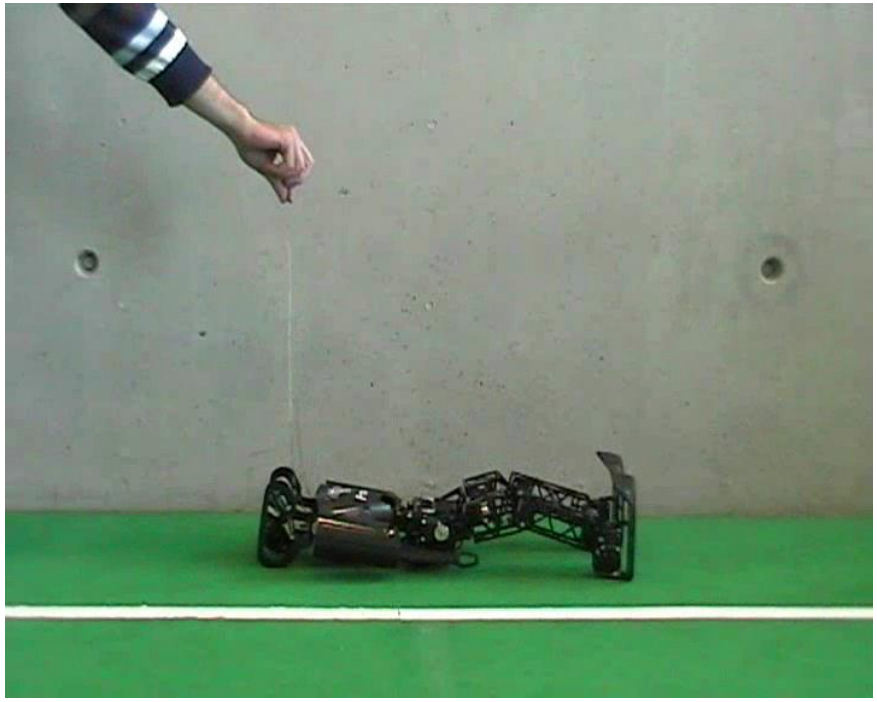




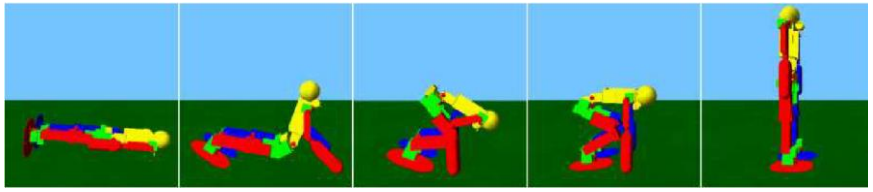
Getting-up

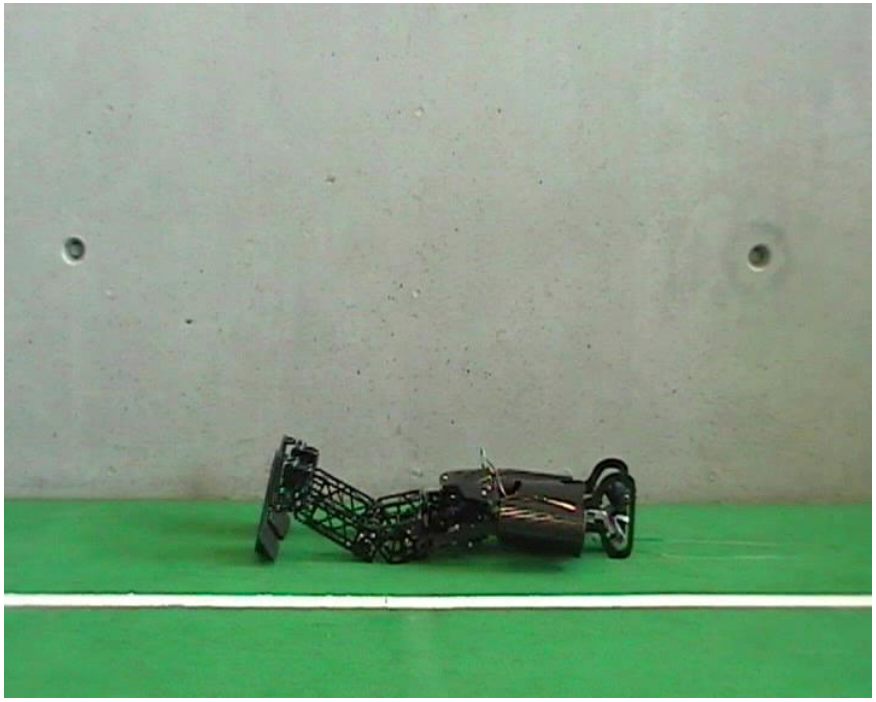
supine





prone





[Stückler, Schwenk, Behnke: IAS-2006]

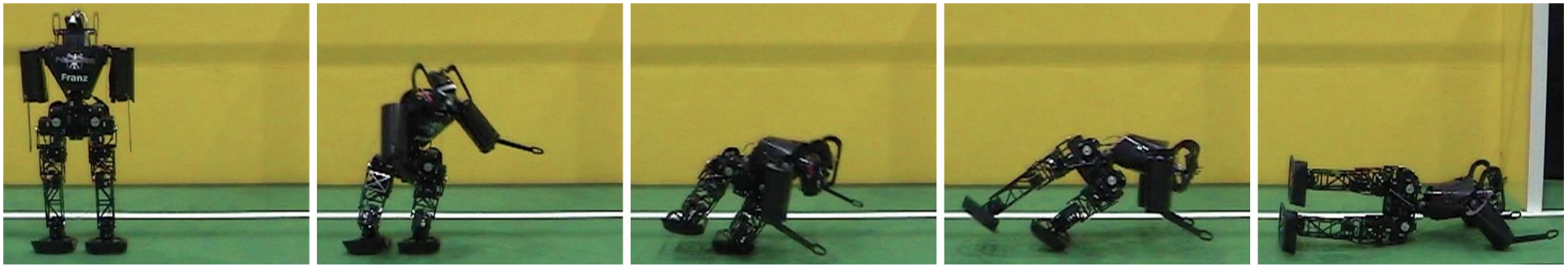
RoboCup 2013 Final

Igus Humanoid Open Platform

[Allgeuer et al. Humanoids 2015]

Goalie Diving Motion

- NimbRo KidSize 2006 Robots; Bodo, Atlanta 2007



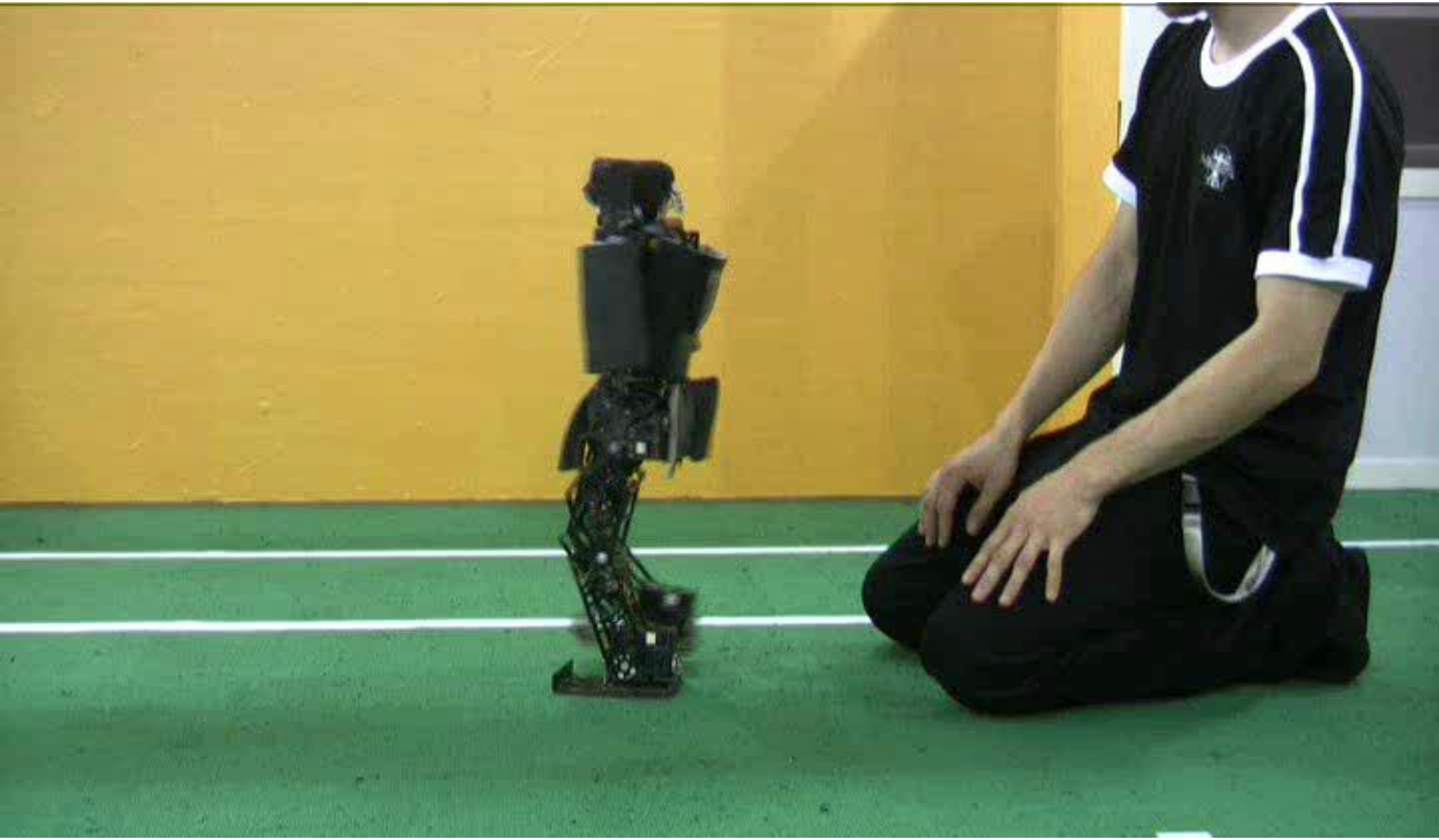
- Dynaped, Graz 2009

[Missura, Wilken, Behnke: RoboCup 2010]

RoboCup 2007 TeenSize Final NimbRo vs. Pal Technology

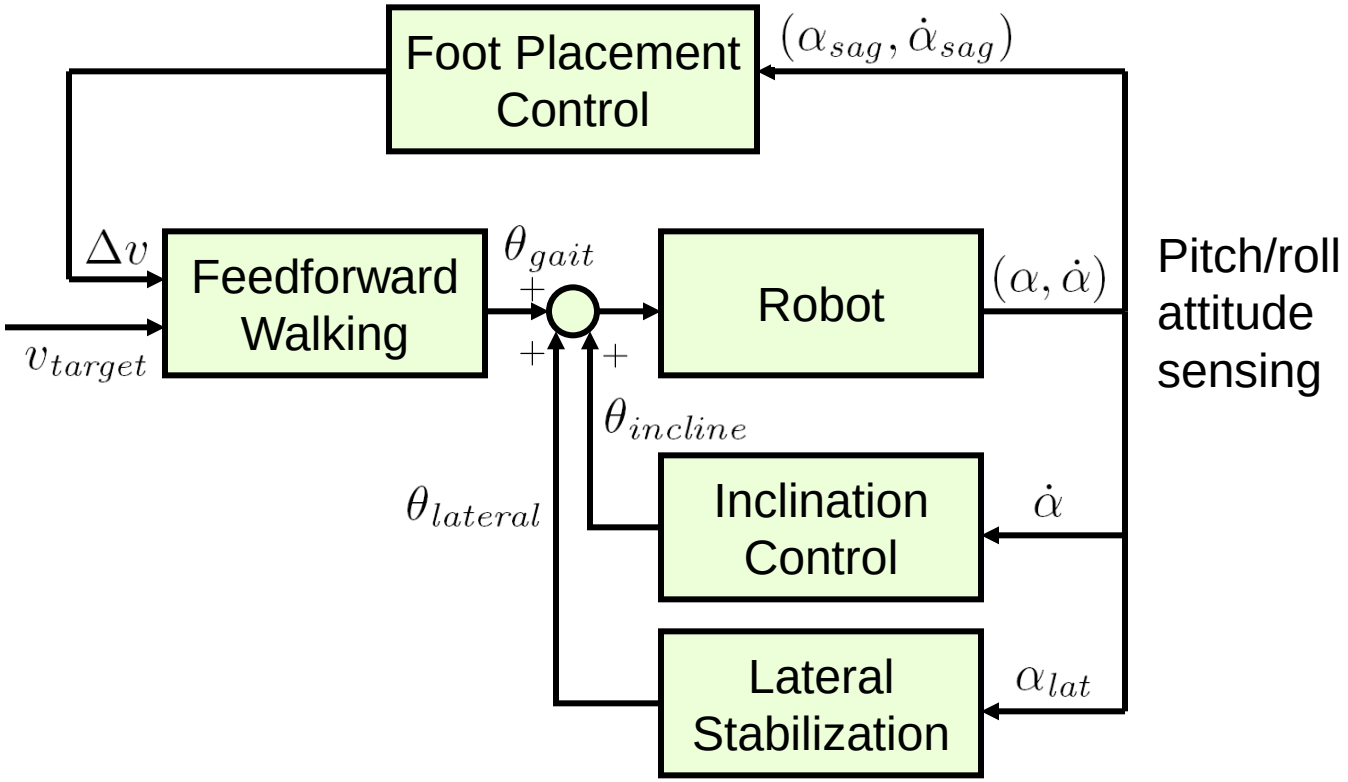
RoboCup 2009 TeenSize Dribble&Kick

Dynamic Walking Stabilization



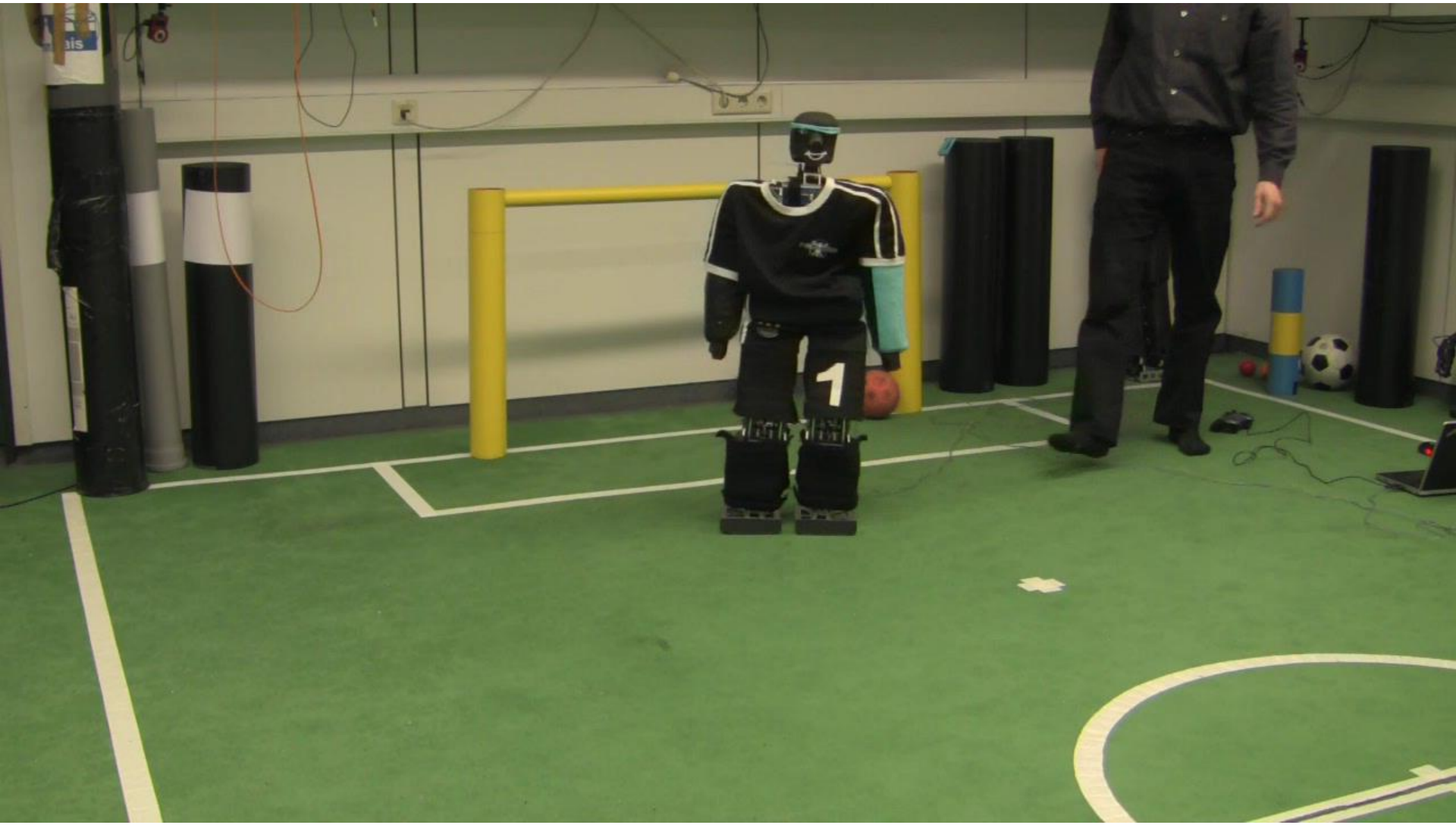
[Behnke et al. RoboCup 2009]

Gait Stabilization Control



[Behnke et al. RoboCup 2009]

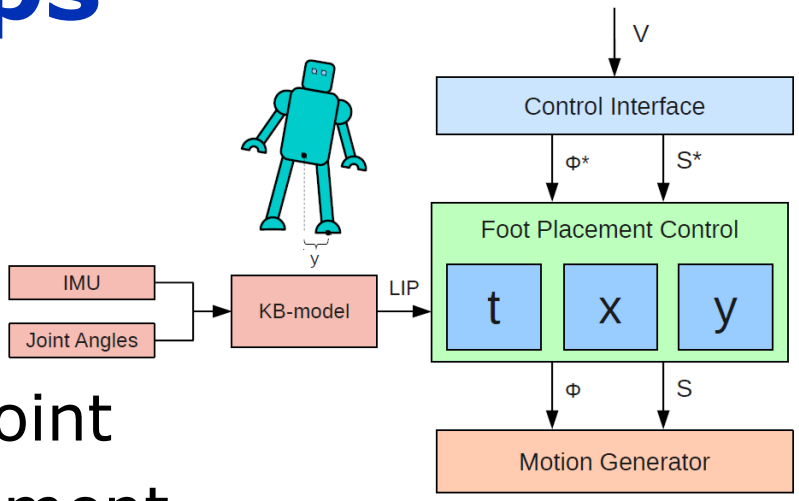
Lateral Sensitivity

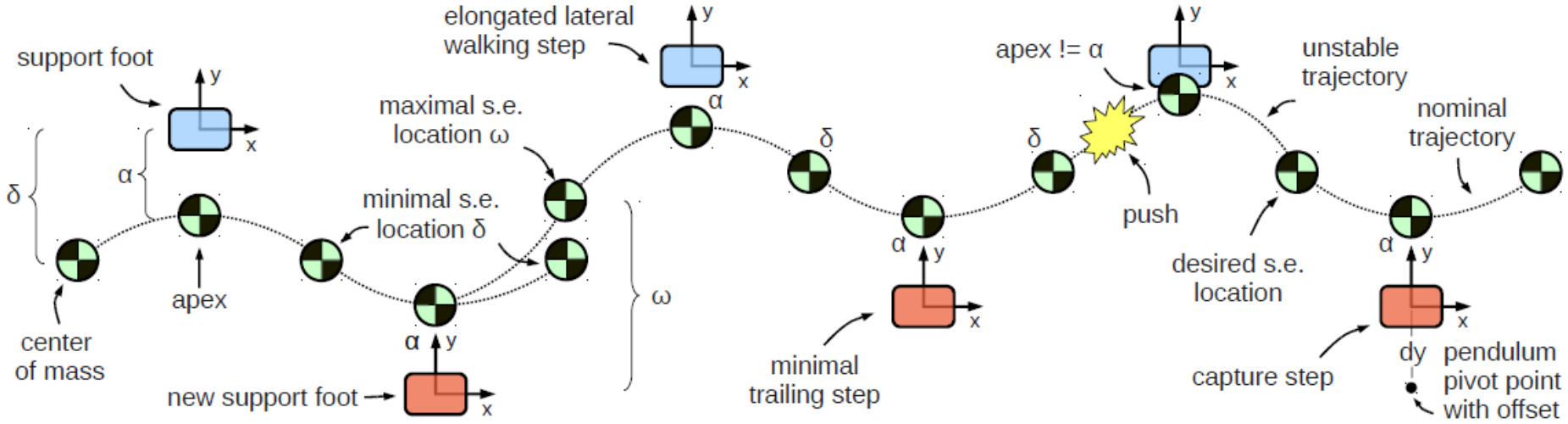


[Missura, Behnke: Humanoids 2011]

Lateral Capture Steps

- Hierarchical control system
- Linear-inverted pendulum model $\ddot{x} = Cx$
- Offset for pendulum pivot point
- Adapt step timing and placement





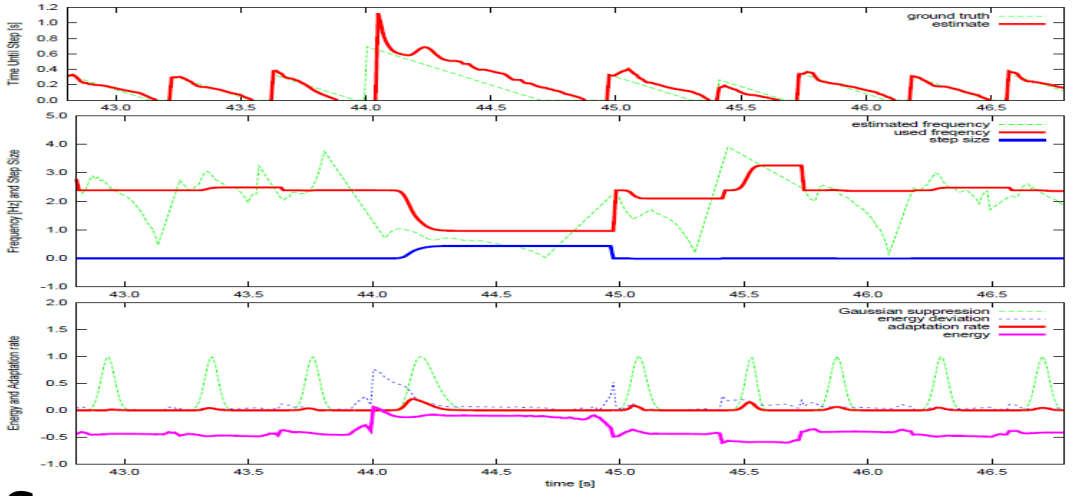
[Missura, Behnke: Humanoids 2011]

Lateral Capture Steps

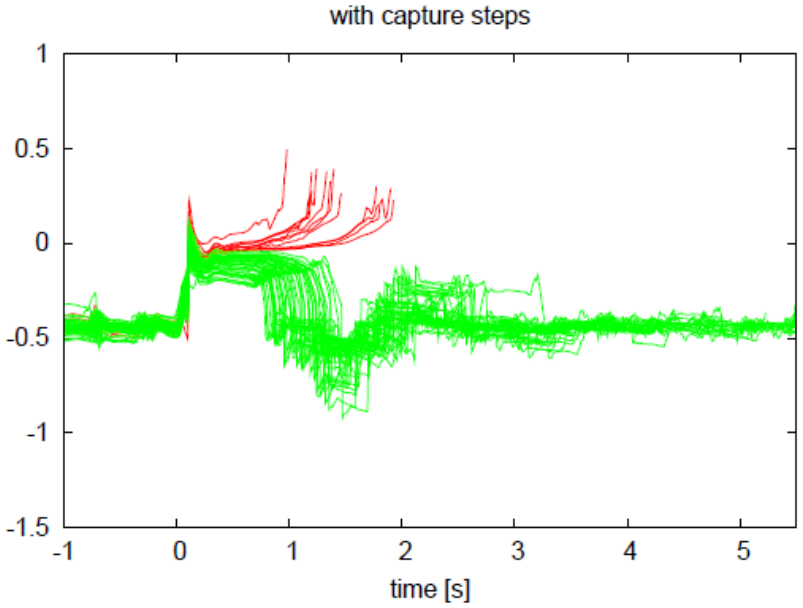
[Missura, Behnke, Humanoids 2011]

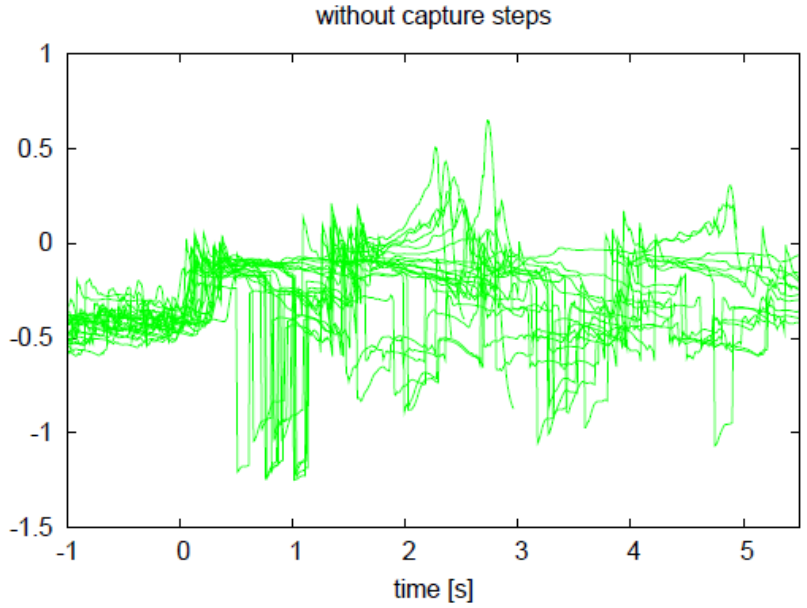
Lateral Capture Steps: Results

- Single disturbance:



- 100 disturbances





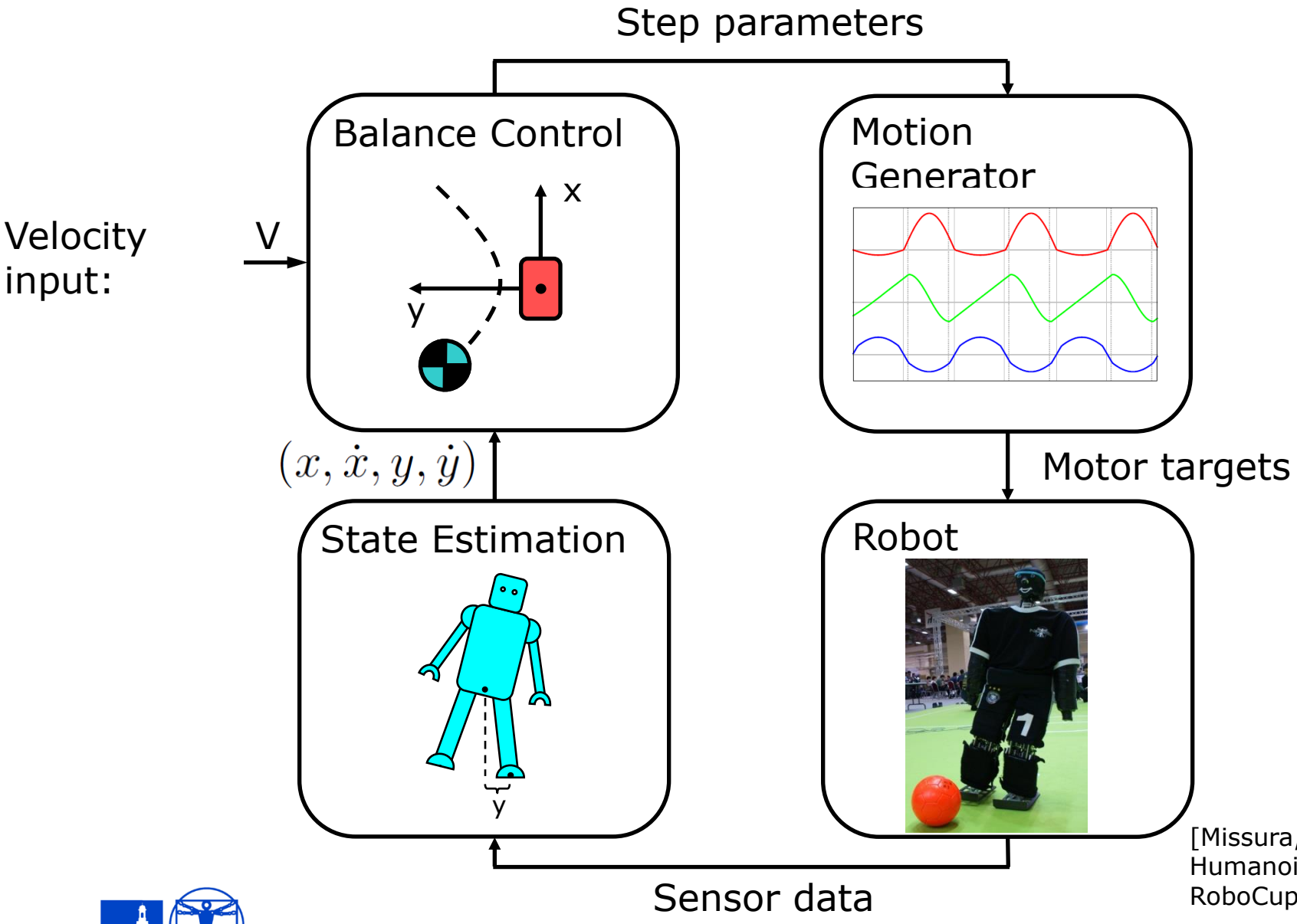
[Missura, Behnke: Humanoids 2011]

Lateral Disturbance Rejection

- Delay step until robot swings back

[Alcarez-Jimenez, et al. RoboCup Symposium 2012]

Capture Step Framework



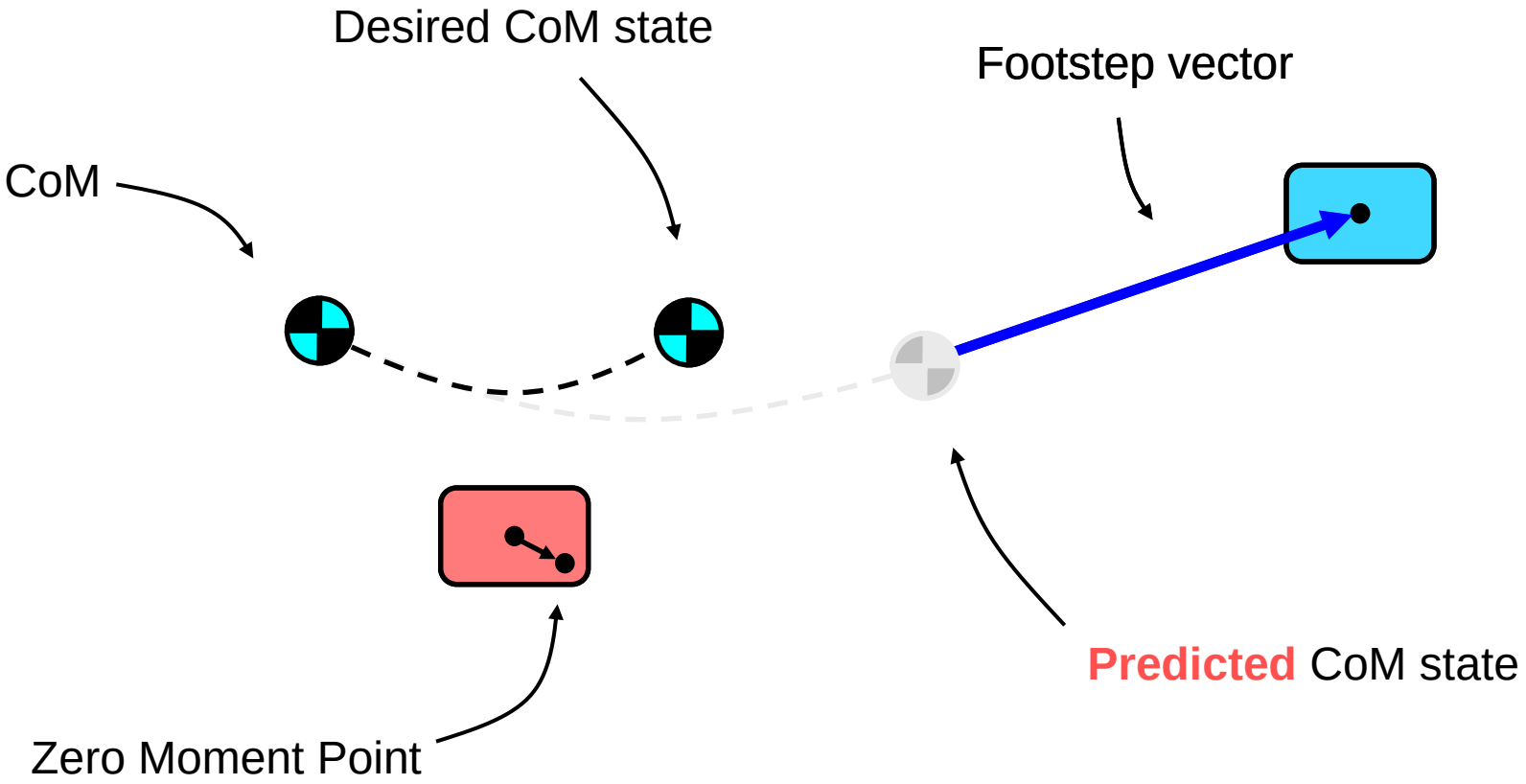
[Missura, Behnke: Humanoids 2013, RoboCup 2014]

Omnidirectional Capture Steps

[Missura and Behnke: Humanoids 2013, RoboCup 2014]

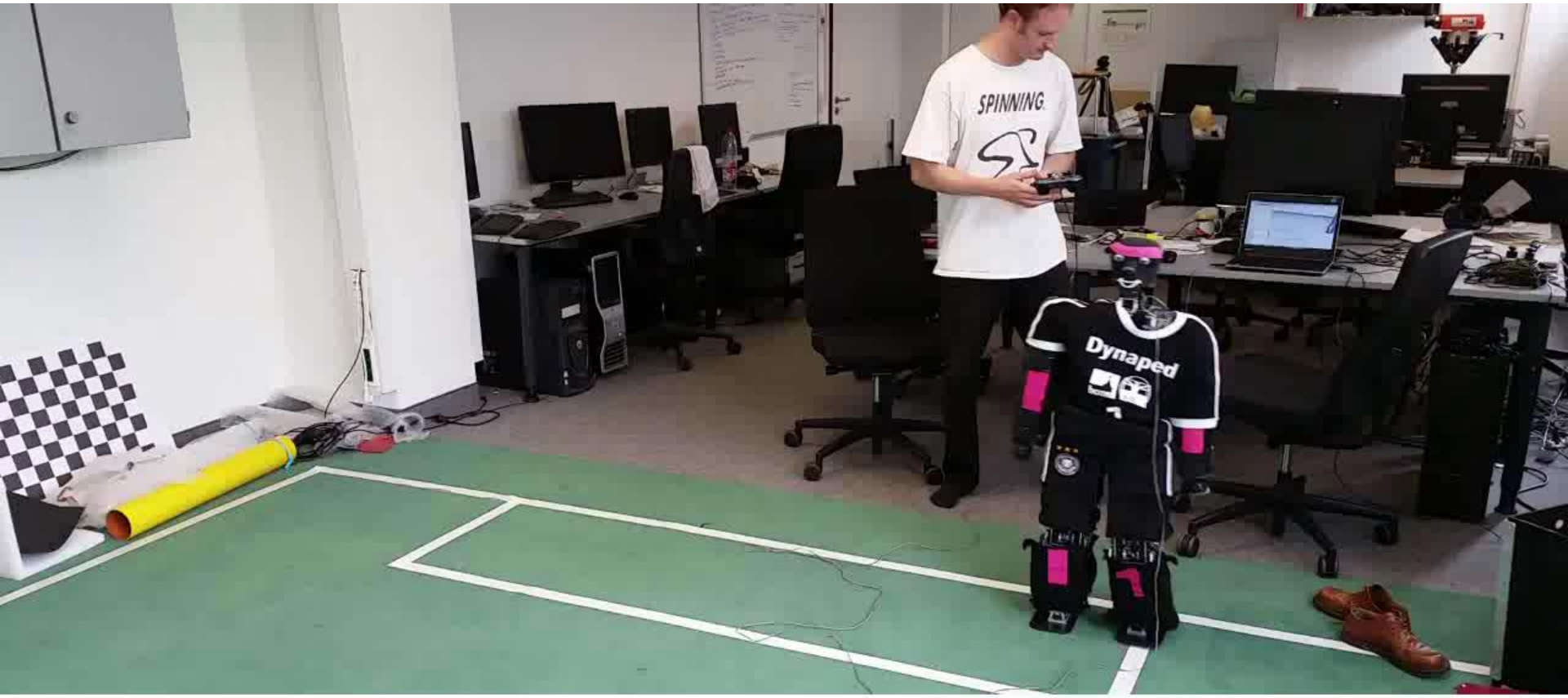
Balance Control

- Adapt ZMP, timing, and foot placement



[Missura and Behnke: Humanoids 2013, RoboCup 2014]

Dynaped with Small Feet



Dynaped with Small Feet

August 2014, Bonn

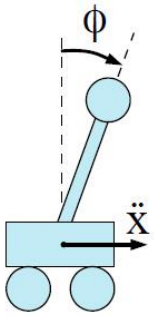
universitätbonn ais

Online Learning of Foot Placement

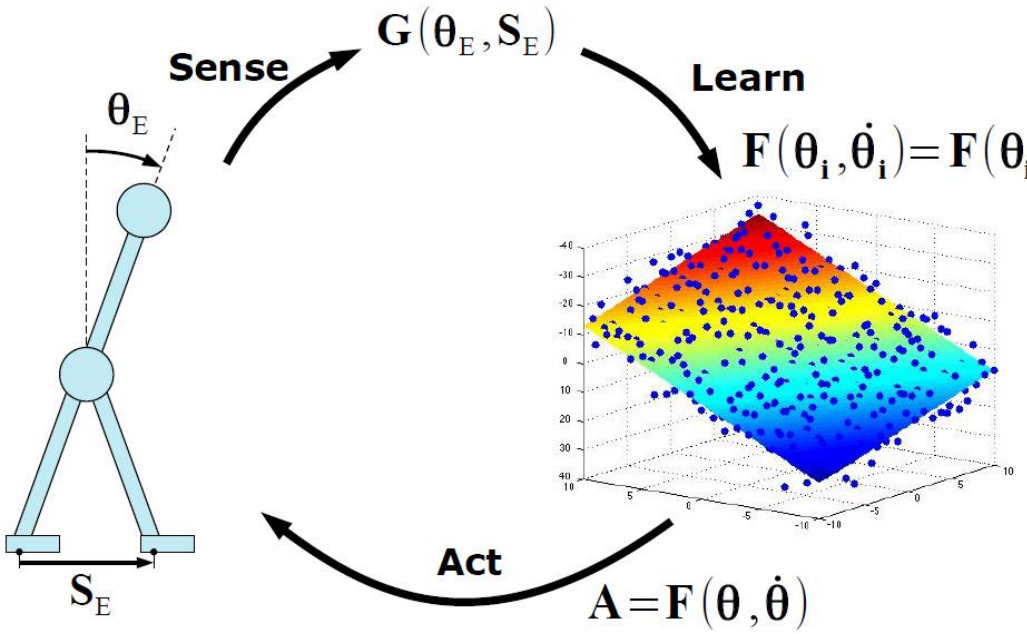
[Missura Behnke: IROS 2015]

Online Learning of Foot Placement

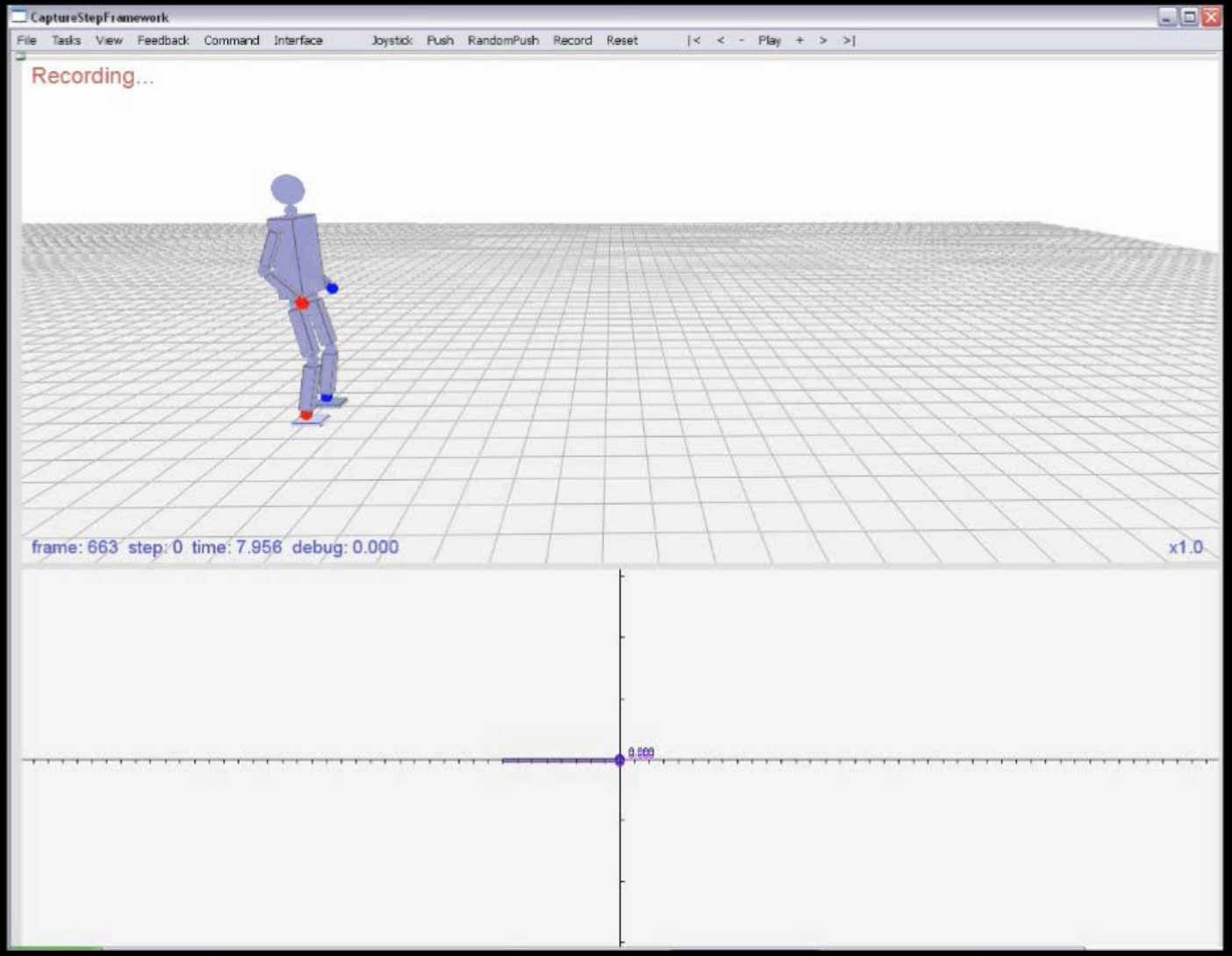
- Function approximator for step size
- Online update based on tilt and step size error



$$\mathbf{G}(\theta_E, S_E) = \theta_E + p_1 \tanh(p_2 S_E)$$



[Missura and Behnke: IROS 2015]


CaptureStepFramework
File Tasks View Feedback Command Interface Joystick Push RandomPush Record Reset |< < - Play + > >|
Recording...
frame: 663 step: 0 time: 7.956 debug: 0.000
x1.0

Online Learning of Foot Placement

[Missura and Behnke: IROS 2015]

Conclusions

- Bipeds are inherently unstable
- Presented some techniques for disturbance rejection and landing
- Disturbances cannot always be rejected
- **Robot must survive the fall!**
- Getting up necessary to continue with task
- Advances needed in
  - Resiliant mechanics (actuators, materials)
  - Reliable state estimation (including terrain)
  - Robust control (fall avoidance, soft landing)