Winning Humanoid Soccer Robots of Team NimbRo: Mechatronics, Perception, Control, and Learning

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Autonomous Intelligent Systems

universitätbonn ais

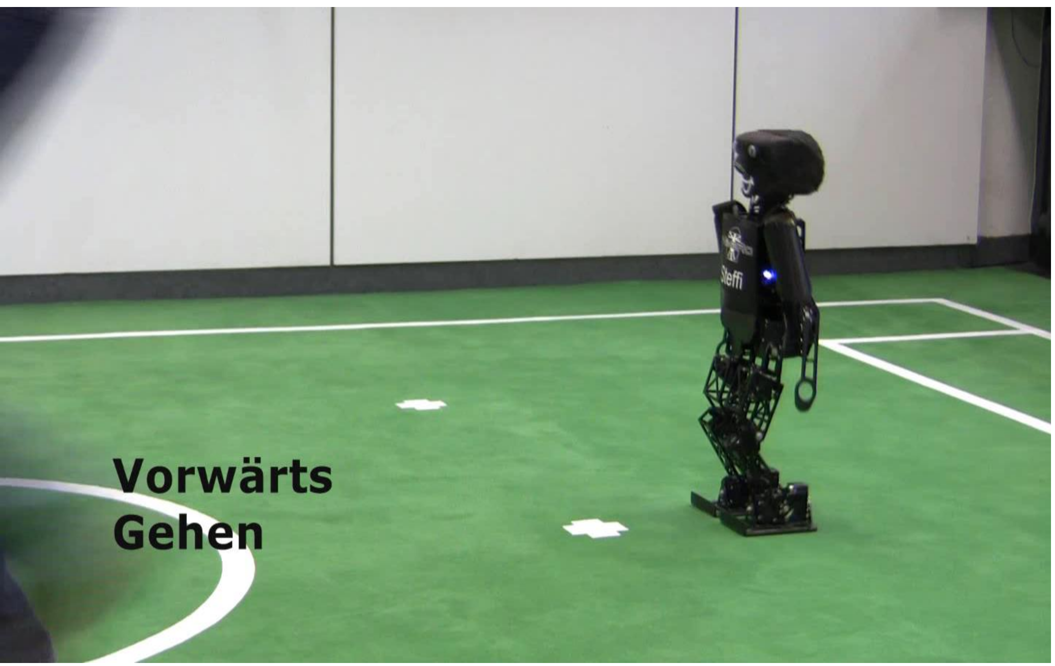
RoboCup German Open 2005

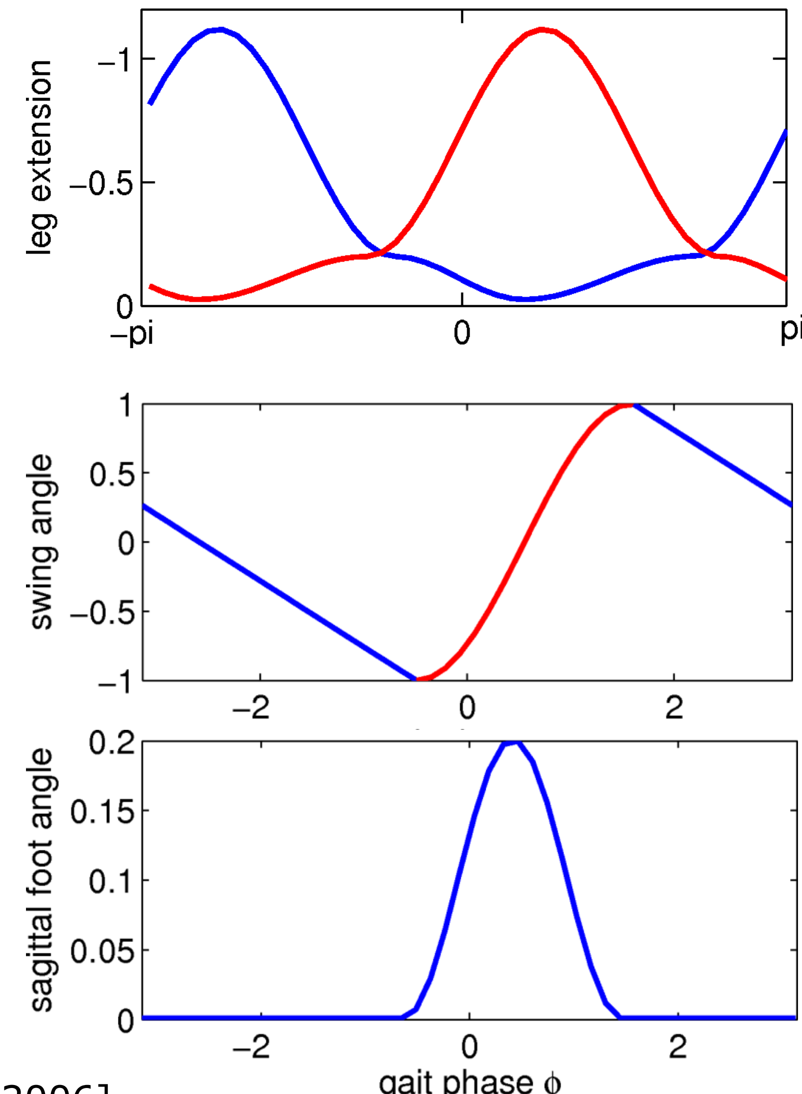
Humanoid Soccer Final RoboCup 2005

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

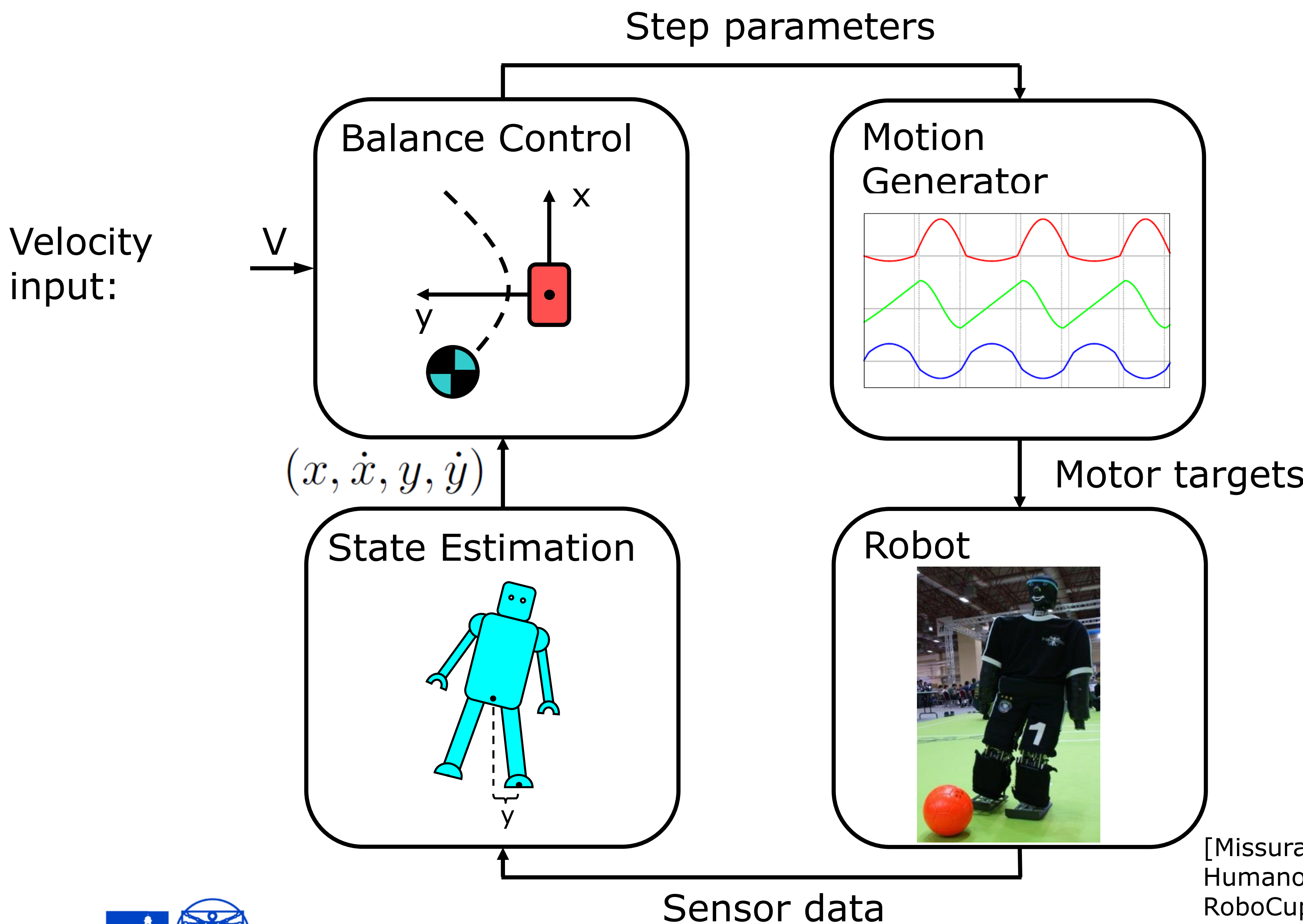




[Behnke: ICRA 2006]

RoboCup 2013 Final

Capture Step Framework



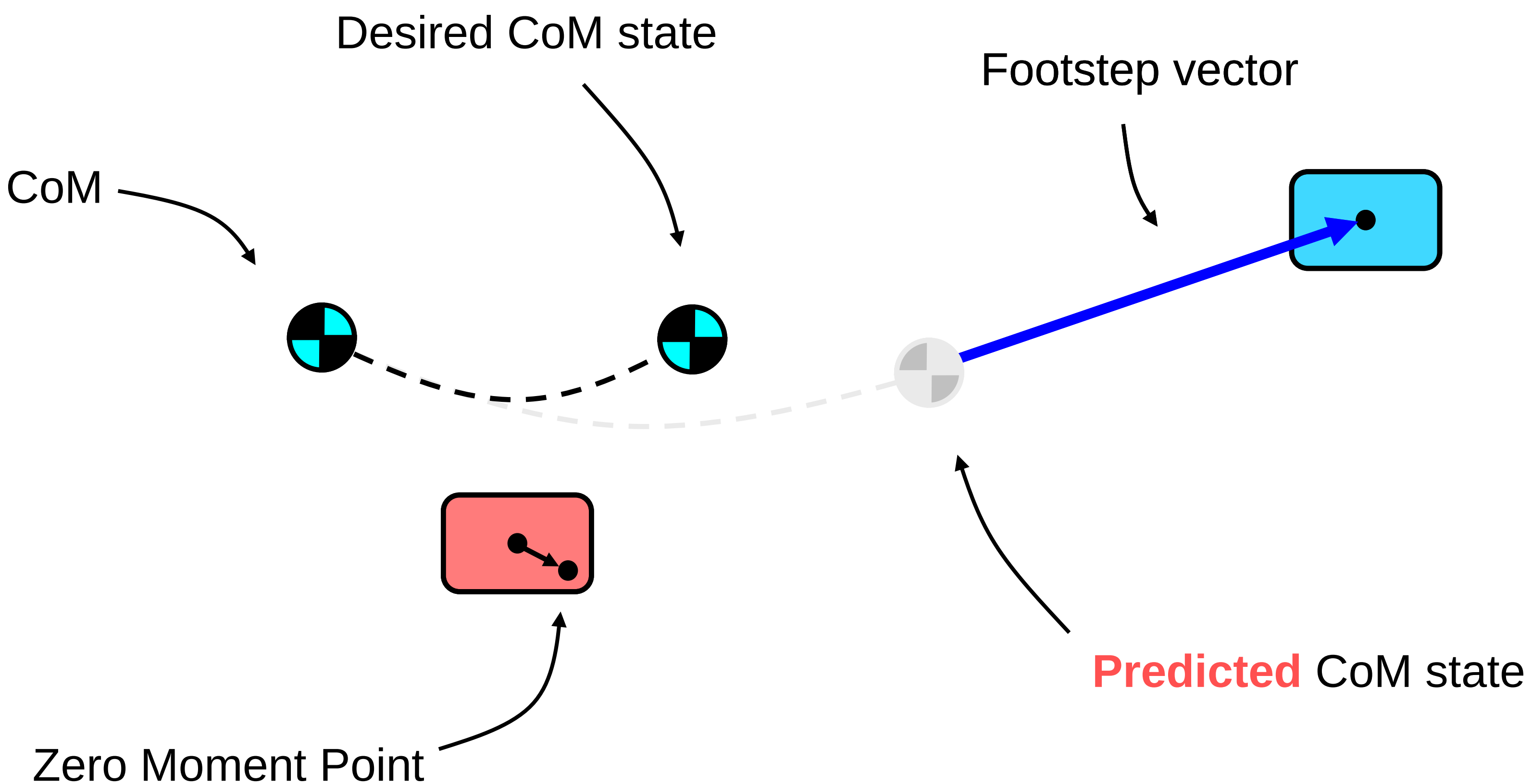
[Missura, Behnke: Humanoids 2013, RoboCup 2014]

Omnidirectional Capture Steps

[Missura and Behnke: Humanoids 2013, RoboCup 2014]

Balance Control

- Adapt ZMP, timing, and foot placement



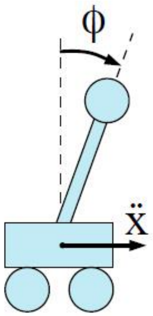
[Missura and Behnke: Humanoids 2013, RoboCup 2014]

Dynaped with Small Feet

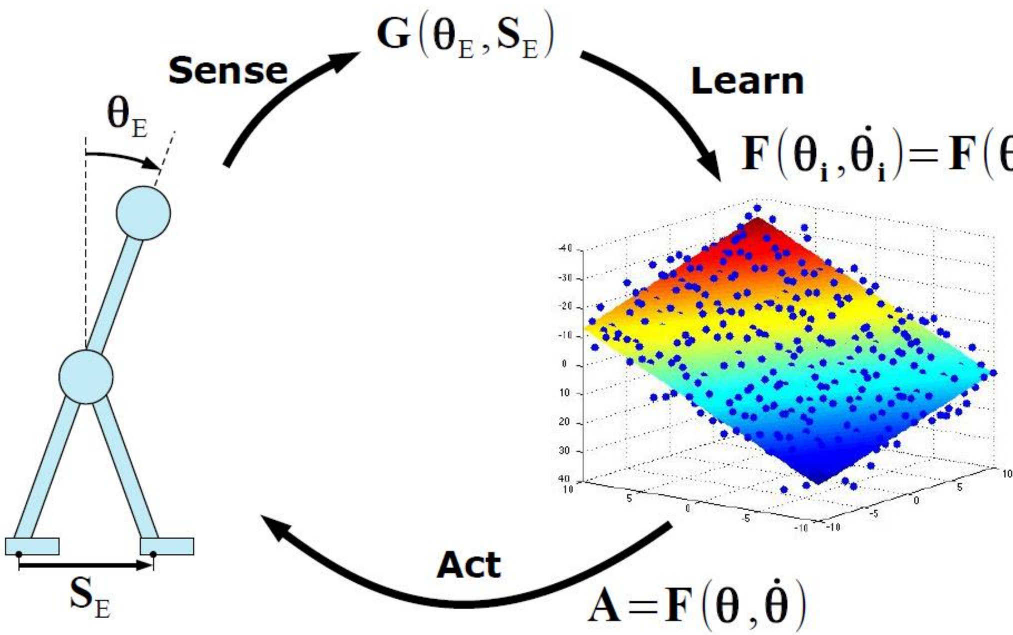
[Missura and Behnke: Humanoids 2013, RoboCup 2014]

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]

Online Learning of Foot Placement

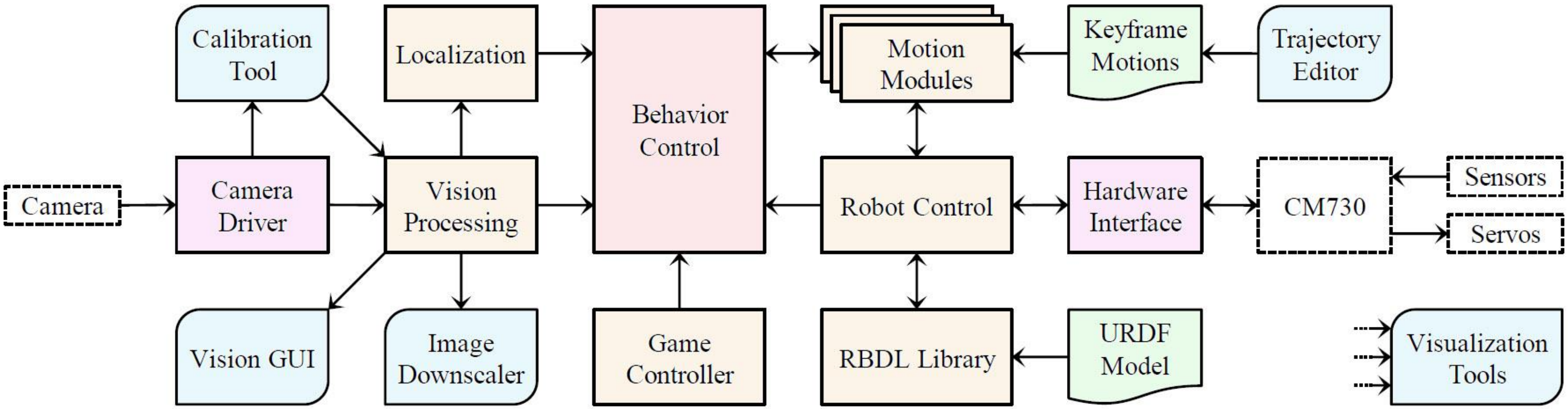
[Missura and Behnke: IROS 2015]

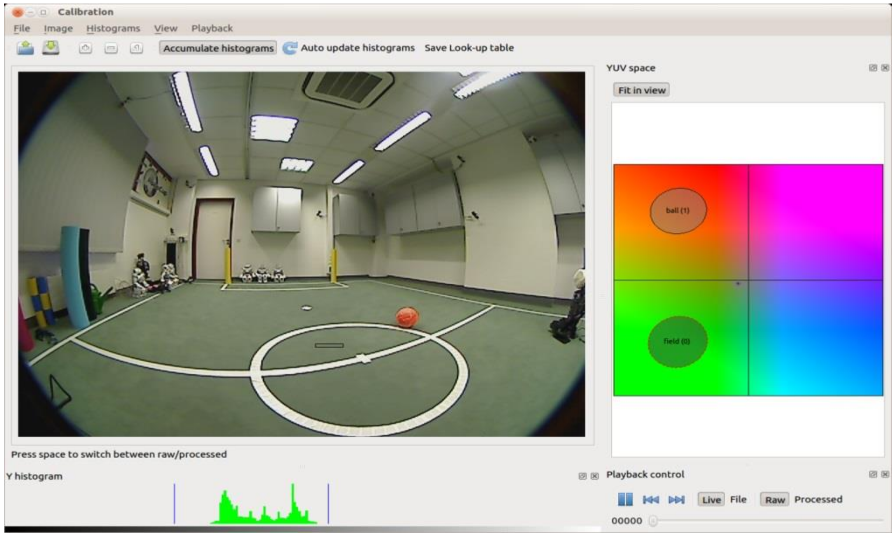
igus Humanoid Open Platform

- 90 cm, 6.6 kg
- 3D printed structure
- 20 DoF
- Dual-core PC
- Wide-angle camera(s)
- IMU
- ROS-based software
- Hard- and software released: nimbro.net/OP

[Allgeuer et al. Humanoids 2015]

ROS-based Software

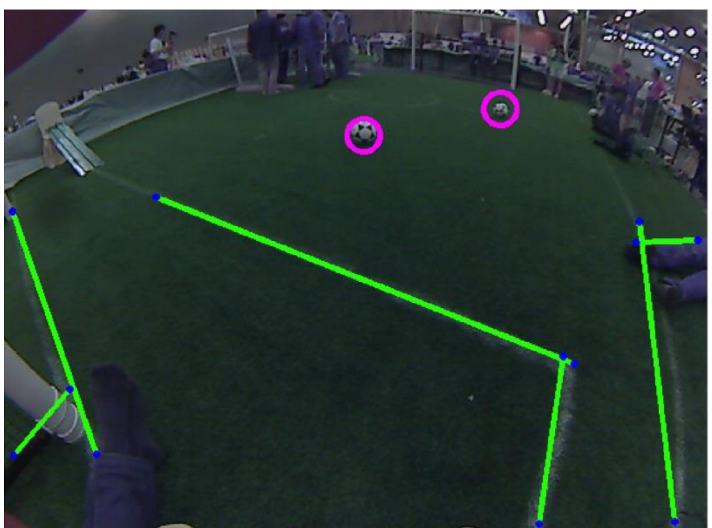


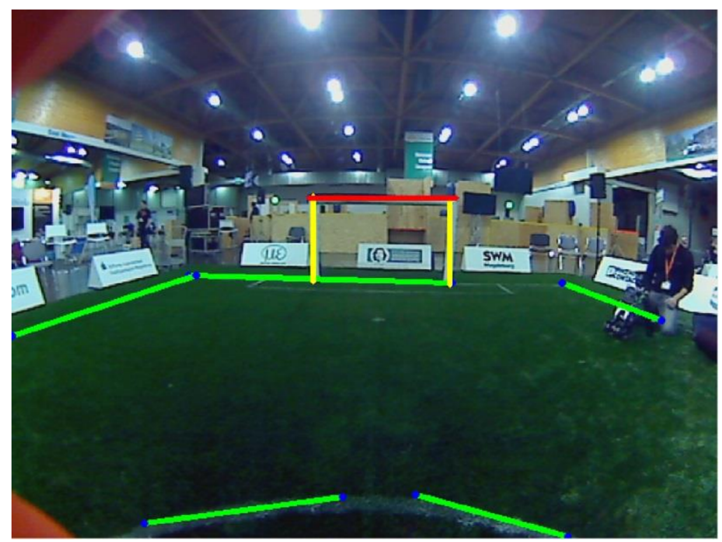


[Allgeuer et al. Humanoids 2015]

Perception of the Game Situation

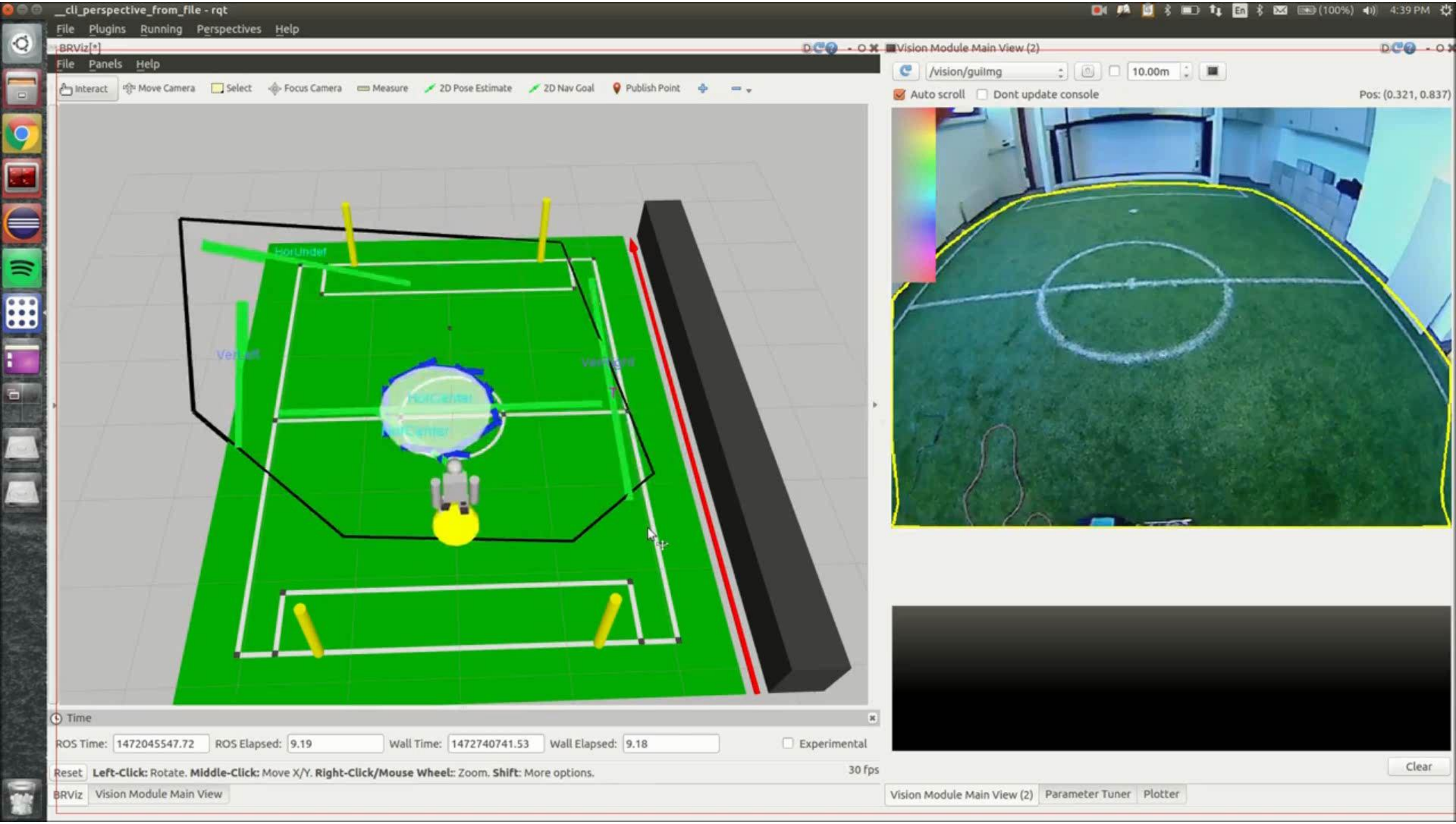
- Less relying on color
- Learned ball detection
- Goal detection





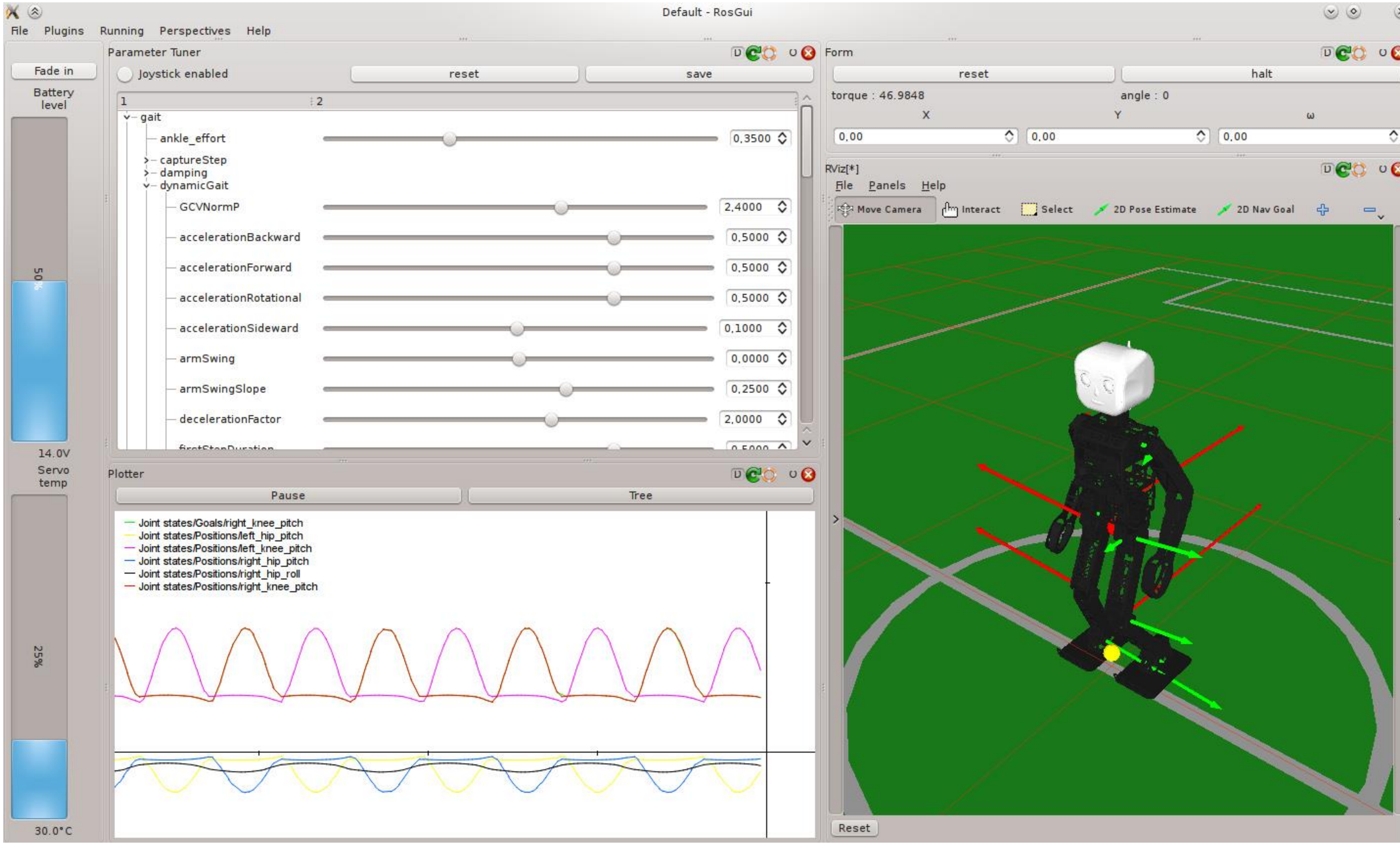
[Farazi et al. Humanoid Soccer Workshop 2015]

Localization



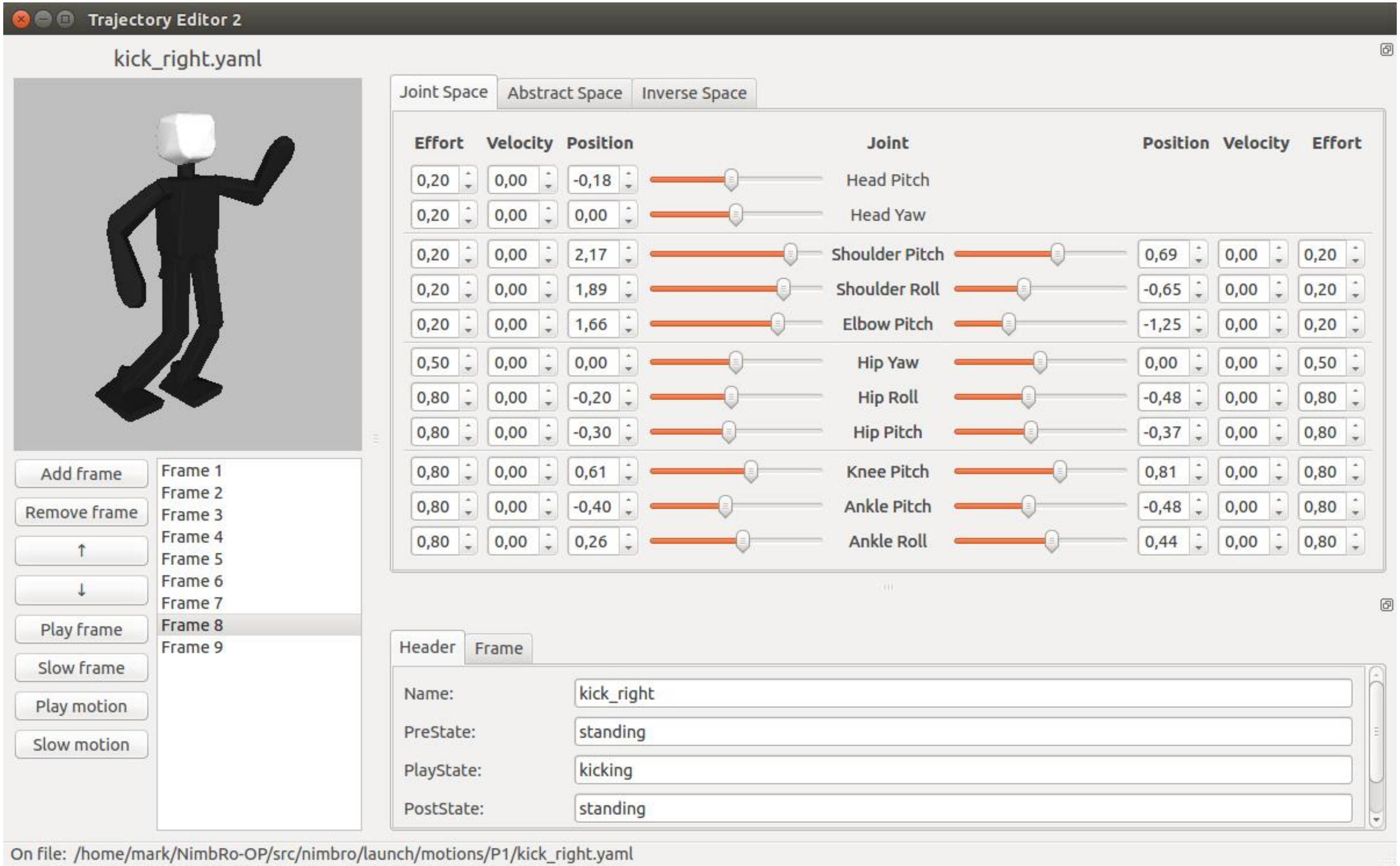
[Farazi et al. Humanoid Soccer Workshop 2015]

Rviz 3D Visualization



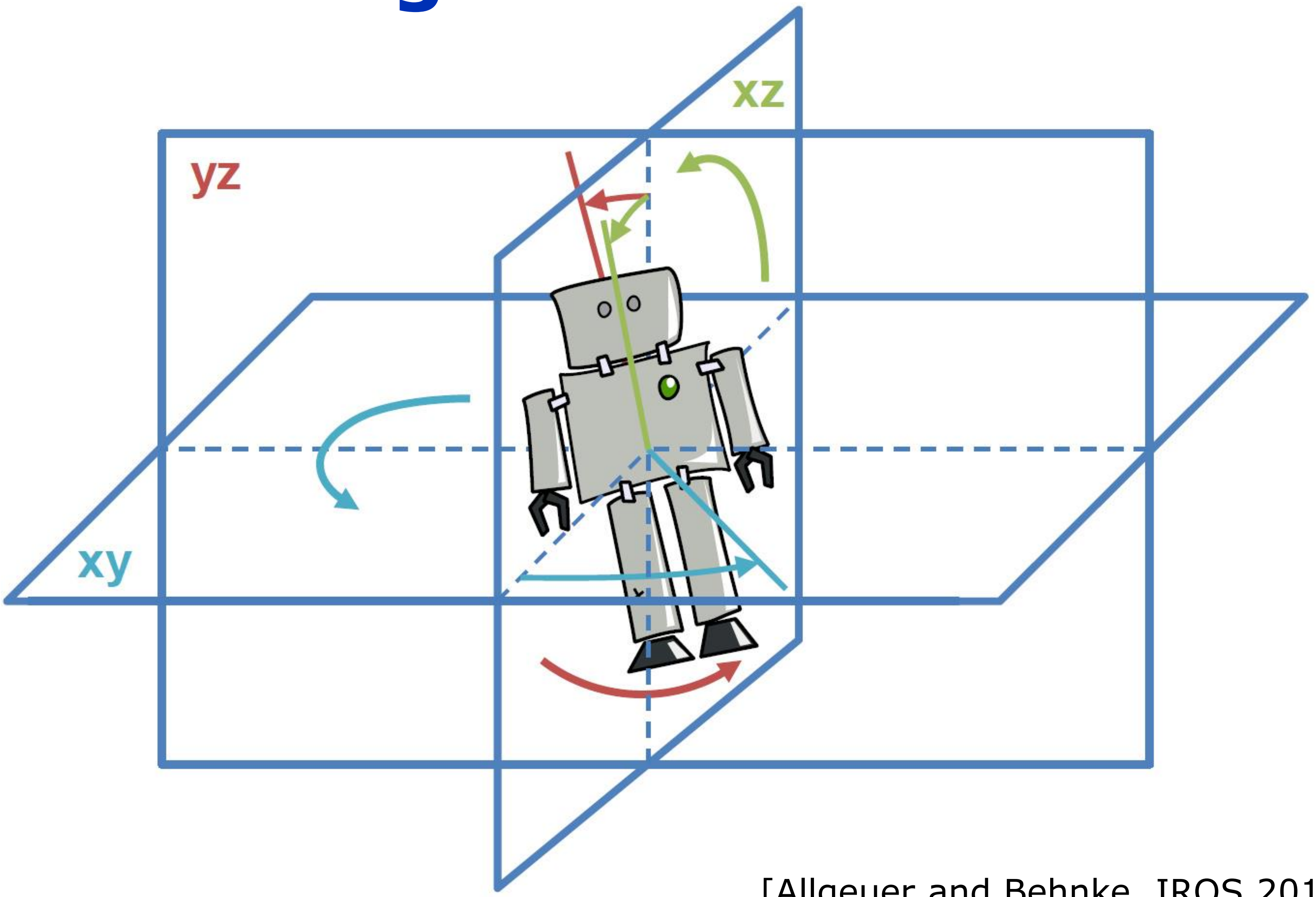
[Allgeuer et al. Humanoid Soccer Workshop 2013]

Trajectory Editor



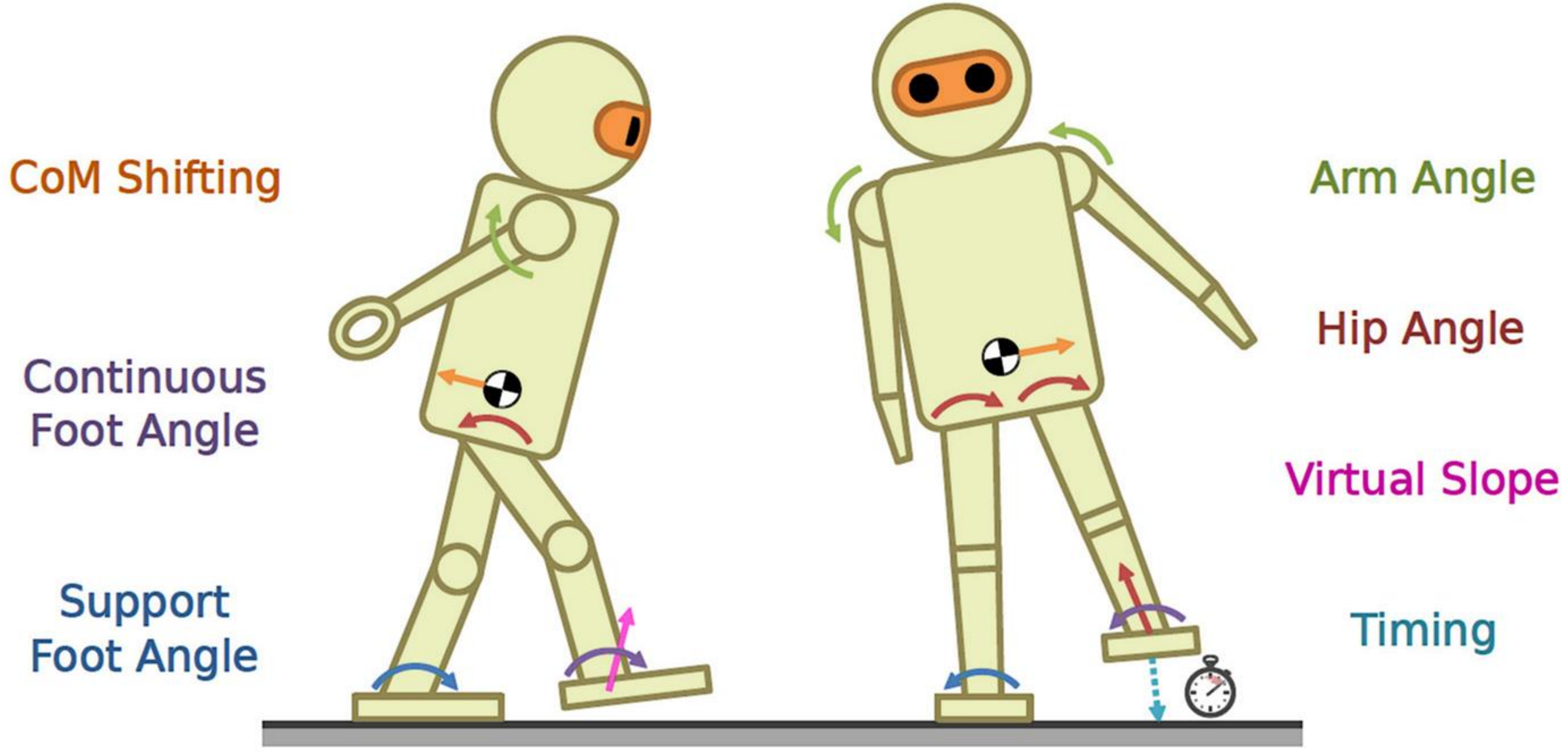
[Allgeuer et al. Humanoid Soccer Workshop 2013]

Fused Angles



[Allgeuer and Behnke, IROS 2016]:

Feedback Mechanisms

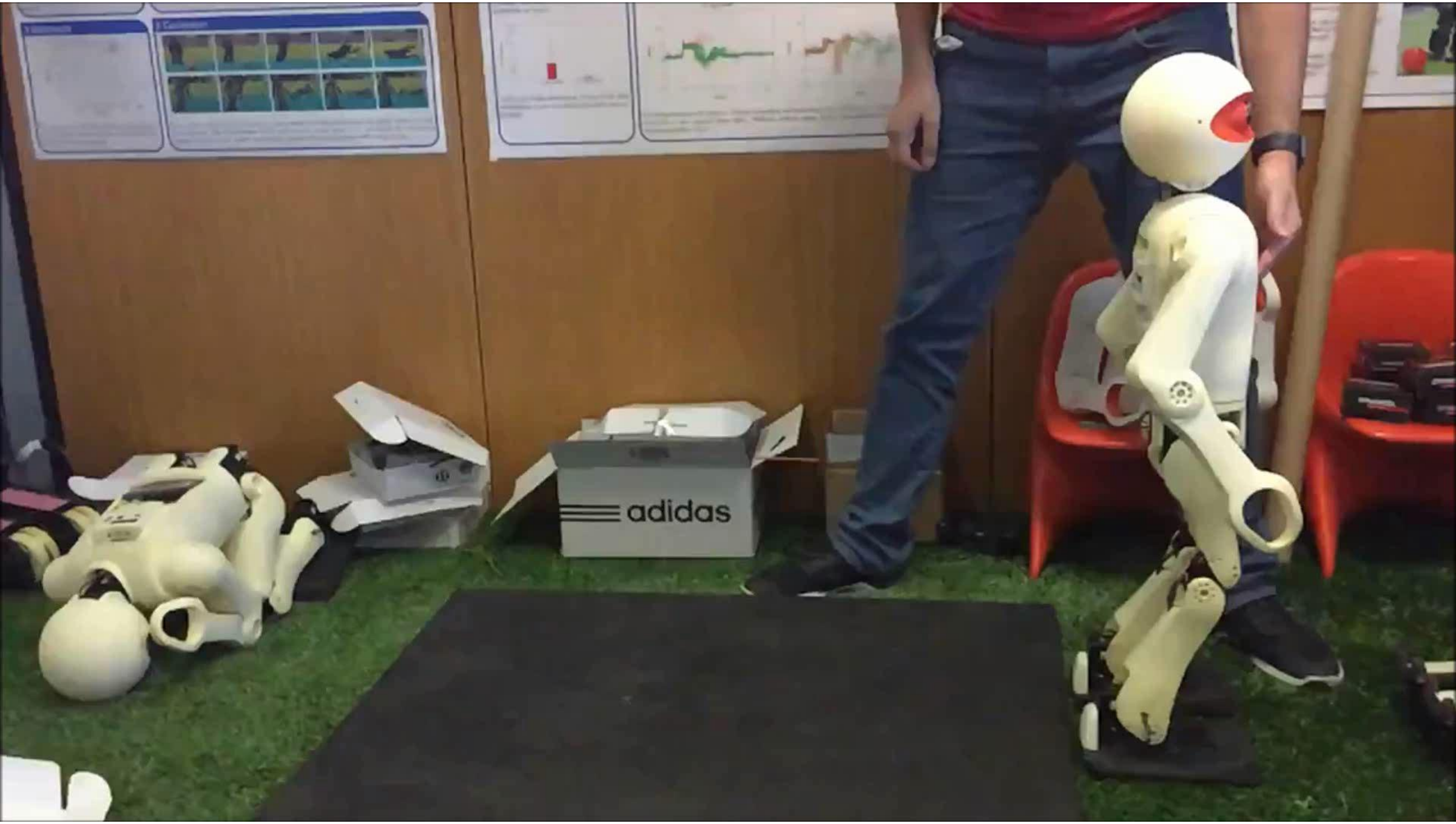


[Allgeuer and Behnke: Humanoids 2016]

PD Feedback

[Allgeuer and Behnke: Humanoids 2016]

Landing Motion Backwards



Landing Motion Forwards

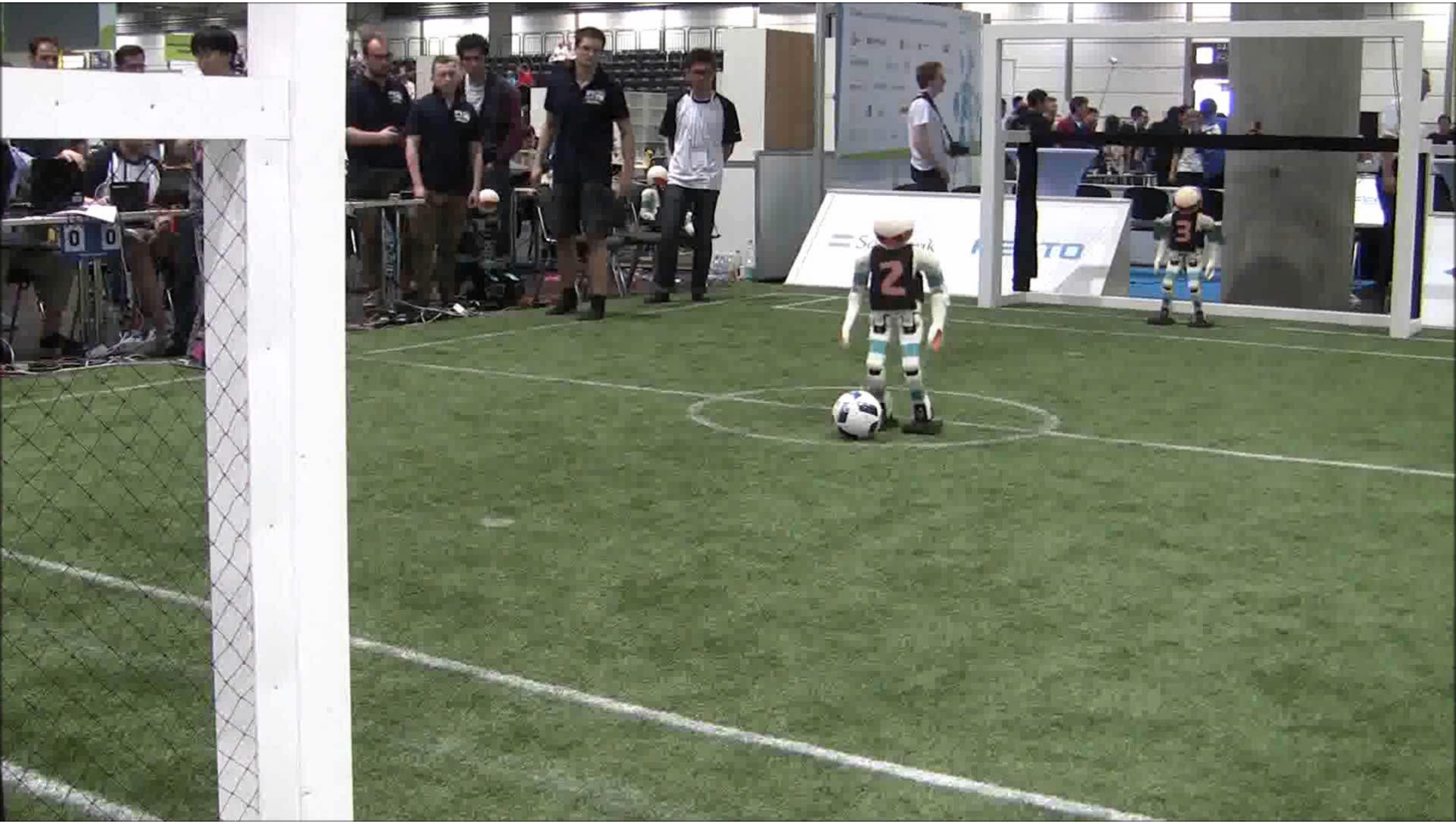
Getting Up

[Allgeuer et al. Humanoids 2015]

Visual Perception

[Farazi & Behnke: Humanoid Soccer Workshop 2015]

RoboCup 2016 TeenSize Final

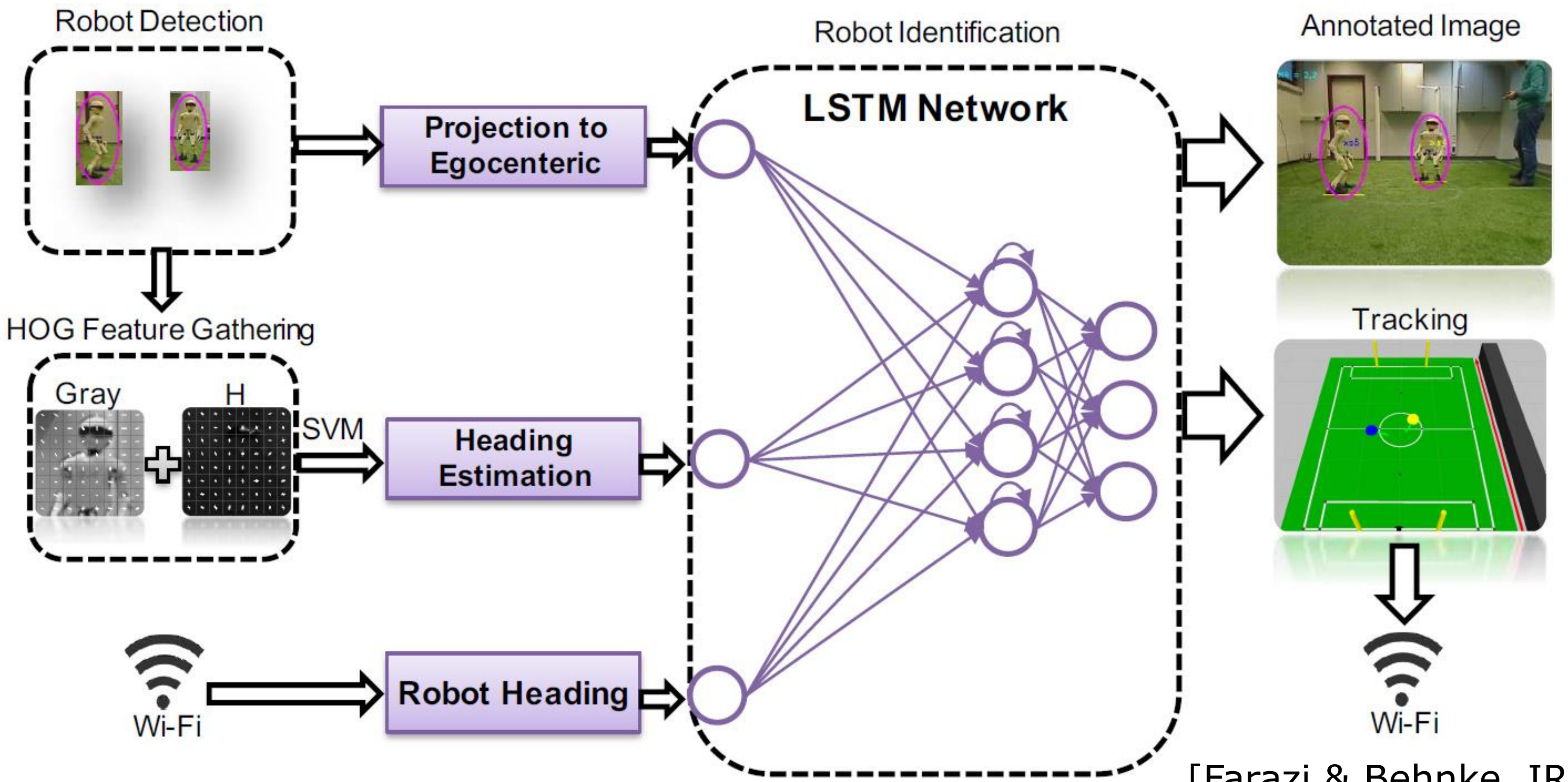


Farazi et al. RoboCup 2016, Robot World Cup XX, 2017.

Team NimbRo TeenSize 2016

Robot Detection, Tracking & Identification

- Based on visual detections and compass
- Learning data association

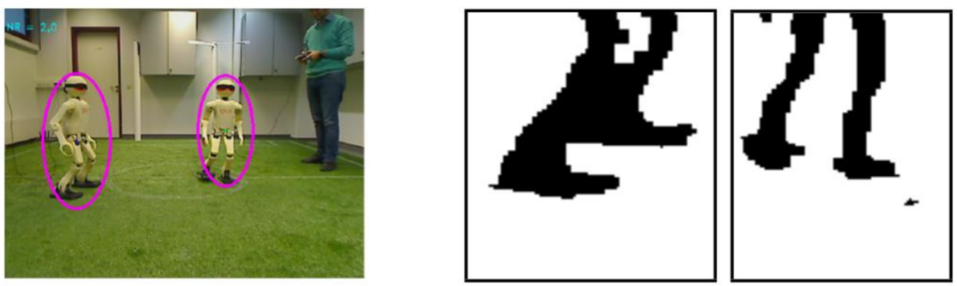


[Farazi & Behnke, IROS 2017]

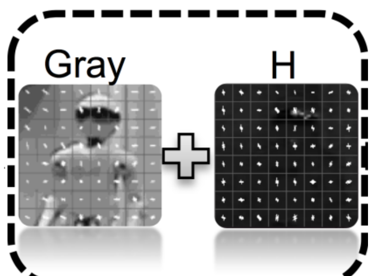
Robot Detection & Pose Estimation

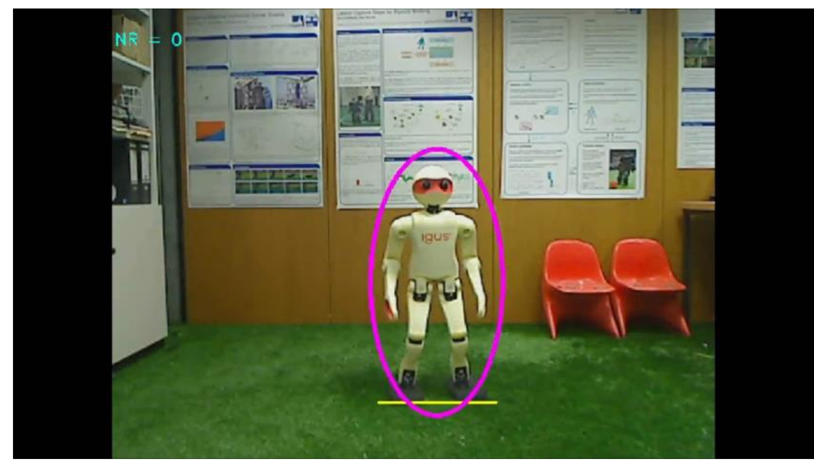
- Based on HoG features

- Scan line feet estimation



- Heading estimation
  - Dense HoG
  - SVM multiclass classifier

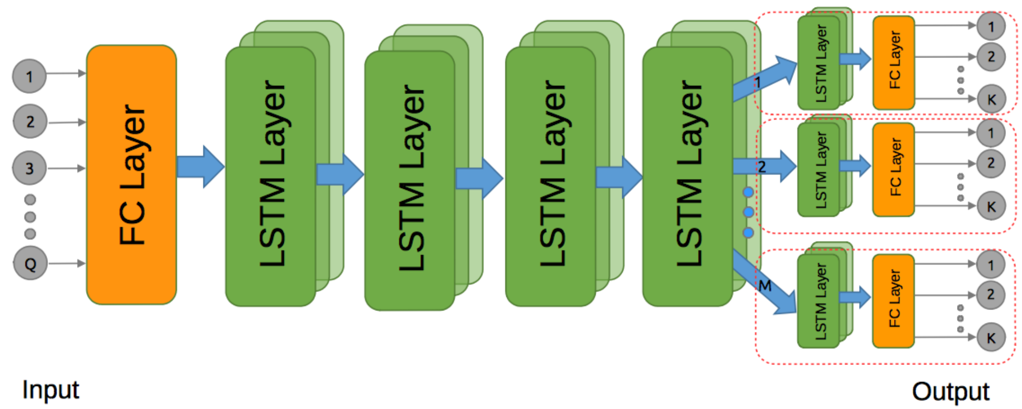


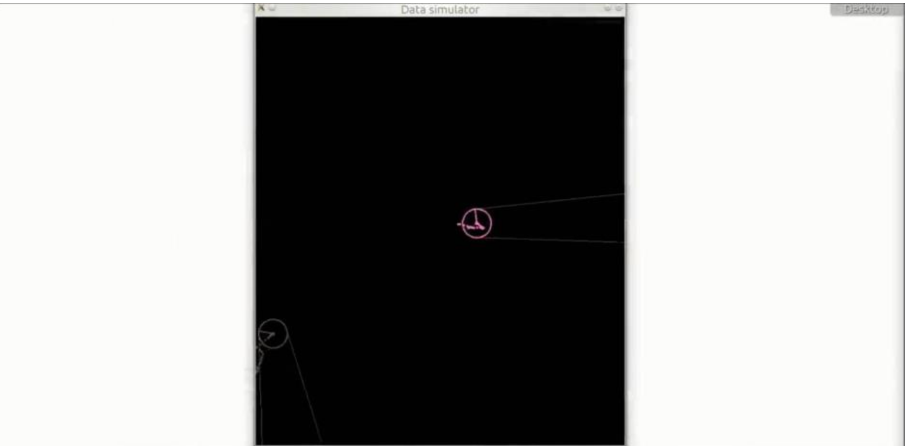


[Farazi & Behnke, IROS 2017]

Learning Data Association

- Recurrent neural network
- Training with simulated data





2D simulator for two robots and three detections

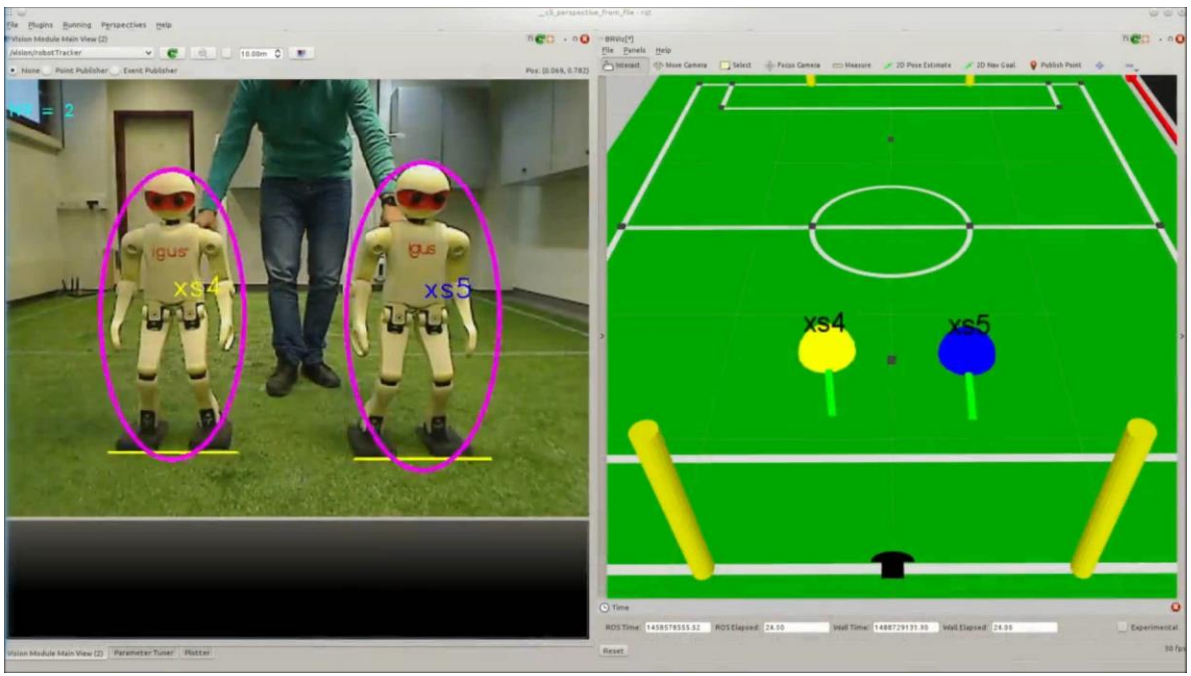
Setup	M=3, N=2	M=5, N=3	M=10, N=7
Human	94.3%	86.3%	**67.3%**
Kalman-HA	75.6%	72.2%	53.1%
ours	**96.2%**	**87.1%**	66.5%

- Fine-tuning on real data

[Farazi & Behnke, IROS 2017]

Real-Robot Experiment

- Three Igus humanoid robots, observer in goal area
- Randomly chosen sequences, 3140 frames in total
- Partial, short term and long term occlusions, Single forward pass 4ms (≈250Hz)

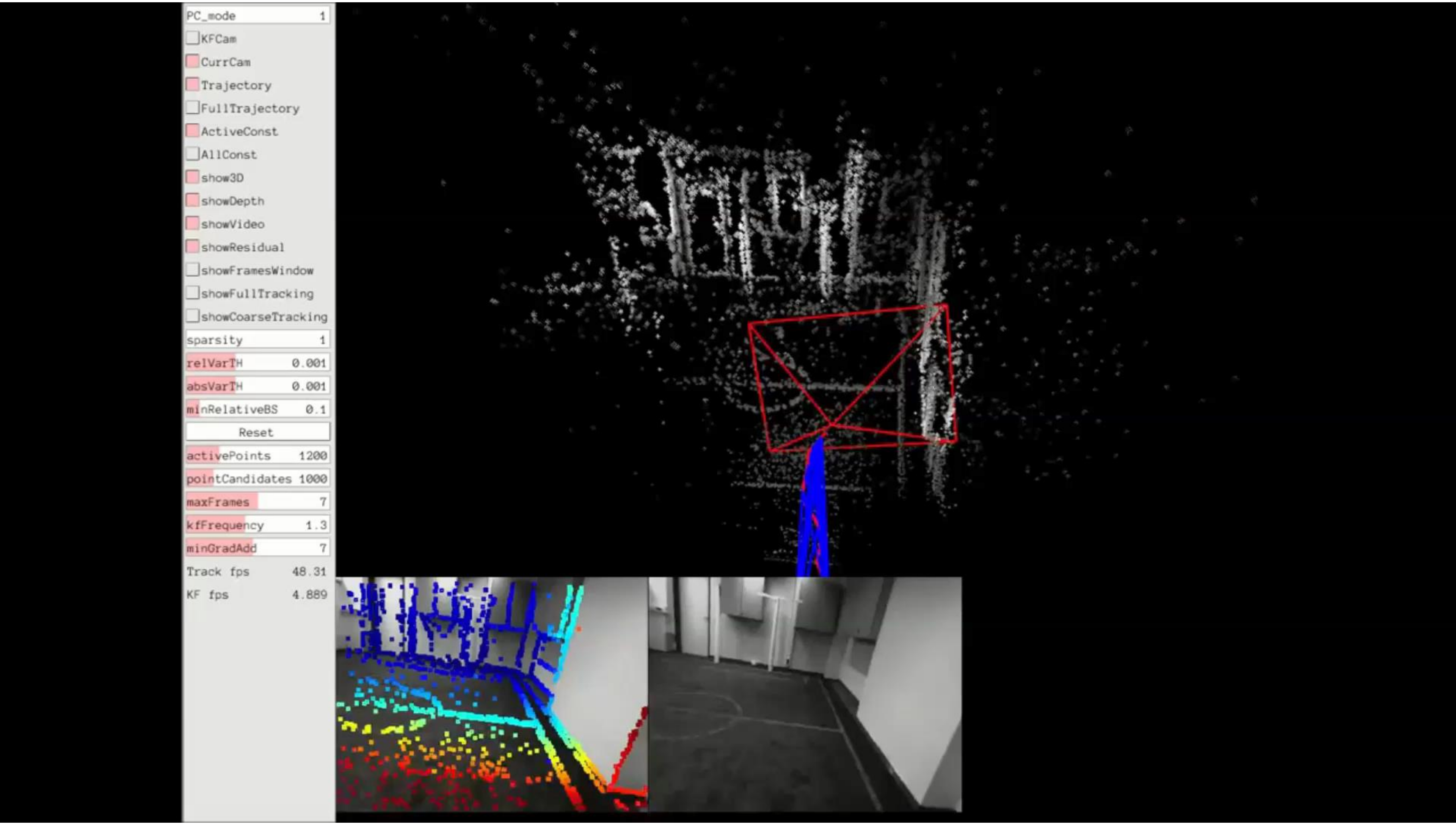


Baseline	Kalman-HA	Kalman-HA2	JPDA	**Ours**
Average error	0.67 m	0.30 m	0.29 m	**0.22 m**

Frames	200	400	800	Total
Kalman-HA	73.2%	75.5%	72.1%	73.8%
Kalman-HA2	87.2%	84.0%	86.3%	85.5%
JPDA	87.1%	84.6%	85.6%	86.3%
Deep LSTM (ours)	**89.8%**	**90.3%**	**92.4%**	**91.1%**

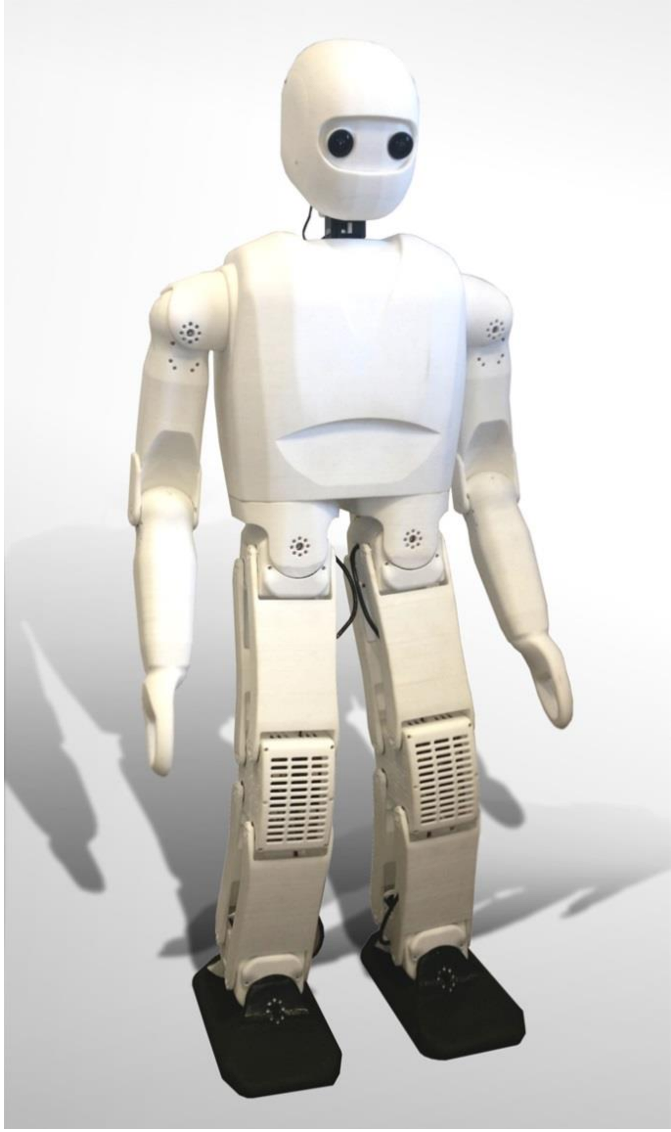
[Farazi & Behnke, IROS 2017]

Direct Sparse Visual Odometry



AlexNet Robot Recognition

NimbRo-OP2

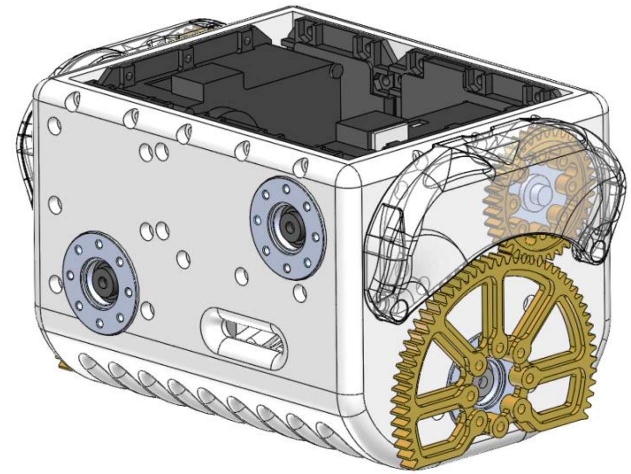


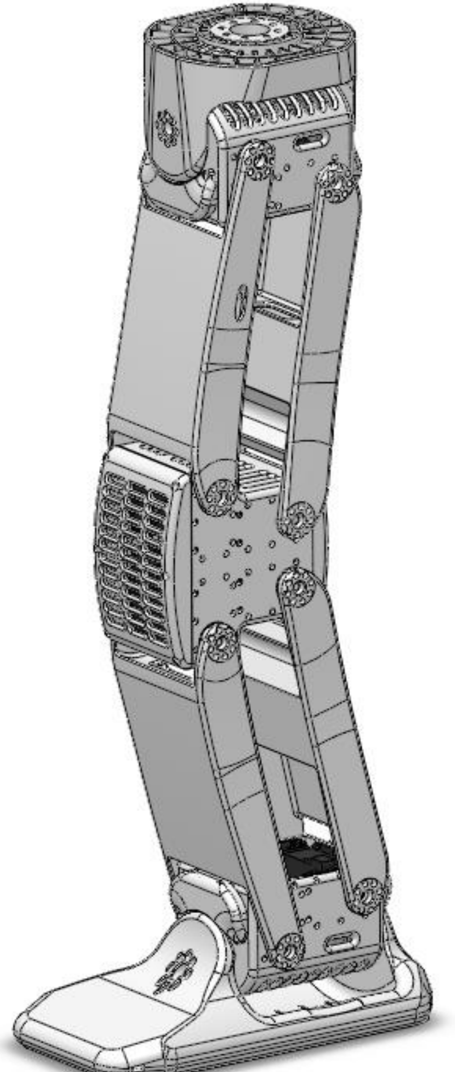
- Height: 135 cm
- Weight: 18.0 kg
- SLS printed exoskeleton
- 18 Degrees of Freedom
  - 5 DoF per leg
    - Parallel kinematics
    - 13 MX-106 actuators
    - Additional spur gears
  - 3 DoF per arm
  - 2 DoF in the neck
- SFF PC i7-7567U 3.5 GHz
- Wide-angle camera
- CM-740 with IMU
- LiPo 14.8 V, 6.6 Ah battery

[Ficht et al. Humanoids 2017]

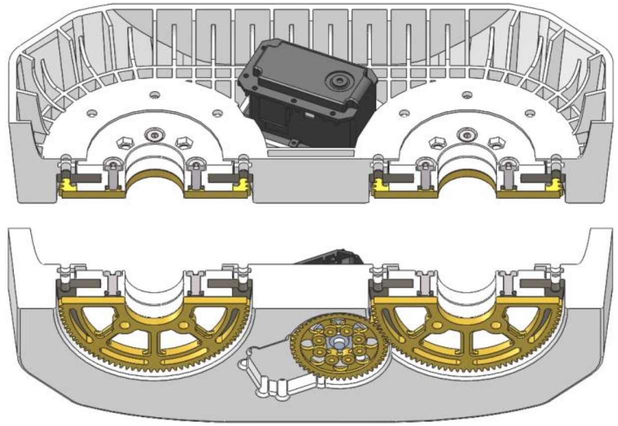
Construction Details

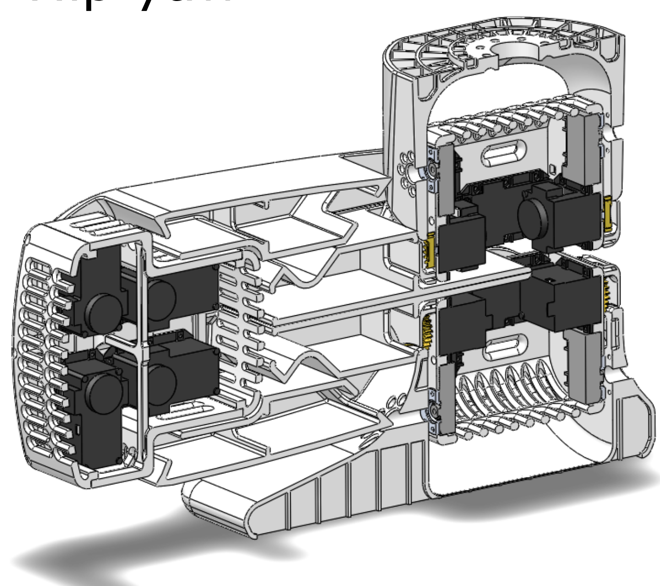
Hip pitch & roll

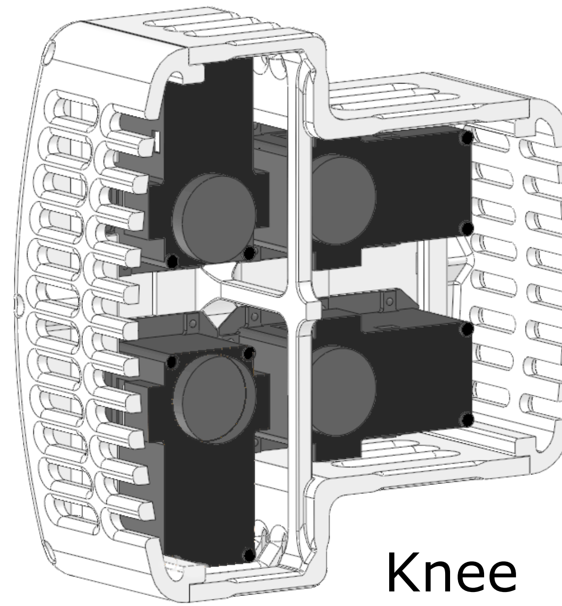




Hip yaw







Knee

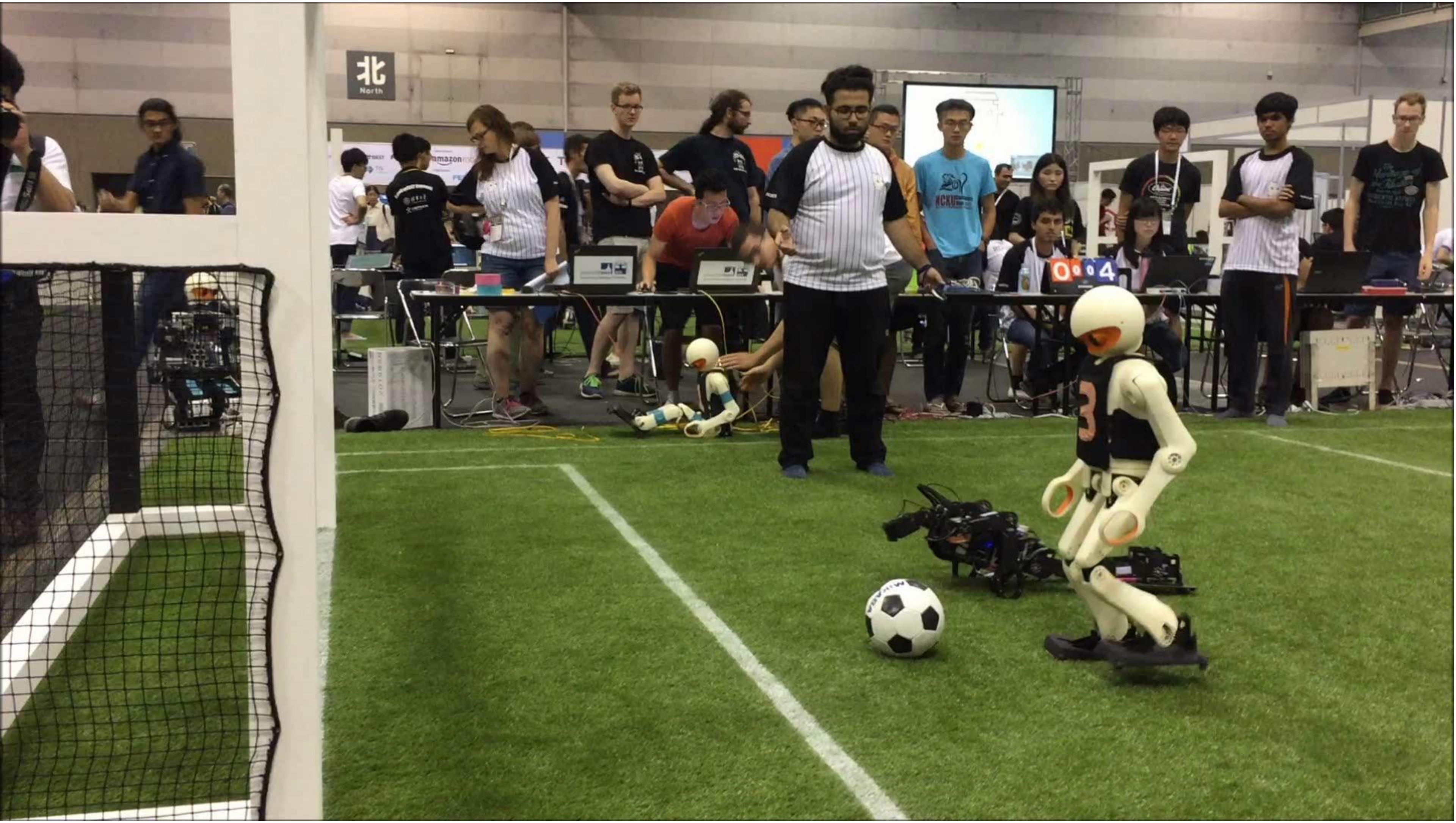
[Ficht et al. Humanoids 2017]

RoboCup 2017 AdultSize Final

[Ficht et al. Humanoids 2017]

RoboCup 2017 AdultSize Technical Challenge

RoboCup 2017 TeenSize



NimbRo RoboCup 2017 Trophies

Conclusions

- Capable robots for Humanoid TeenSize and AdultSize class
- Hard- and Software released
- Many challenges
  - Articulated perception
  - Dynamic full-body motions

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Questions?