Improvements for dynamic simulation models

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Technical Aspects of Multimodal Systems

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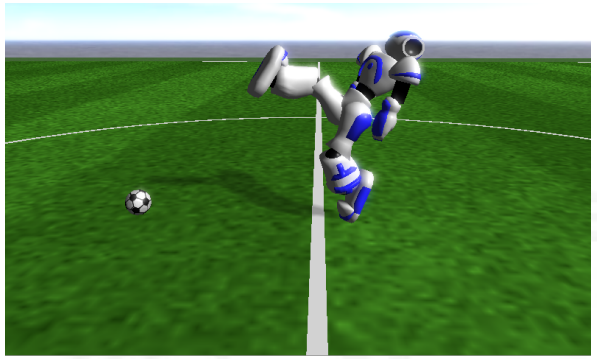
Outline

Motivation

- usage of simulation is intended
  - testing
  - learning
  - optimization
  - protection of hardware
- closing the Reality Gap
- RoboCup: Combination of Leagues



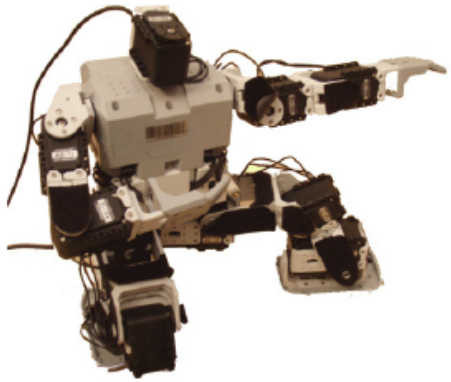
Abdolmaleki, Abbas & Simoes, David & Lau, Nuno & Reis, Luís & Neumann, Gerhard. (2016). Learning a Humanoid Kick With Controlled Distance.

`https://www.robocup.org/system/sub_leagues/images/000/000/023/list/3D.png`

Examples where the Reality Gap is studied

https://www.nanoflowx.com/wp-content/uploads/2018/10/Robotic-Arm_2.png

https://robotliving.com/wp-content/uploads/Aeryon-Scout.jpg



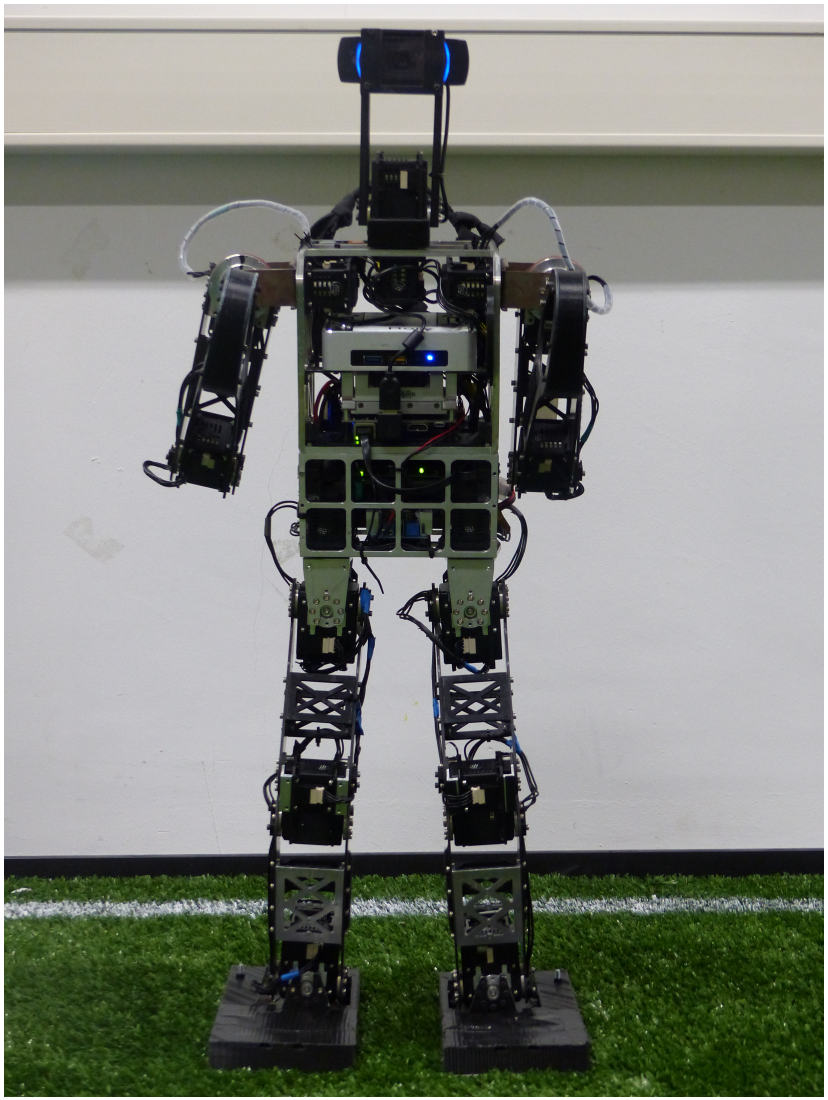
Lima, José; Gonçalves, José; Costa, Paulo; Moreira, António (2009). Humanoid realistic simulator: the servo-motor joint modeling. In 6th International Conference on Informatics in Control, Automation and Robotics, Milan

https://spielgezeug.de/images/brio_34000_labyrinth.jpg

Approaches to close the Reality Gap

- Building actuator model for simulation
- Improve Robot Model
- Adding Noise
- Improve Physics Engine
- Transfer Learning

Wolfgang robot platform



- humanoid robot
- 21 Links
  - Aluminium
  - Carbon
  - PLA
- 20 Joints
  - actuated by Dynamixel MX 64 and MX 106
  - controlled through Rhoban DXL Board
- 2 Onboard Computers
  - Intel NUC
  - Nvidia Jetson TX2
  - ROS usage

Dynamixel Motors

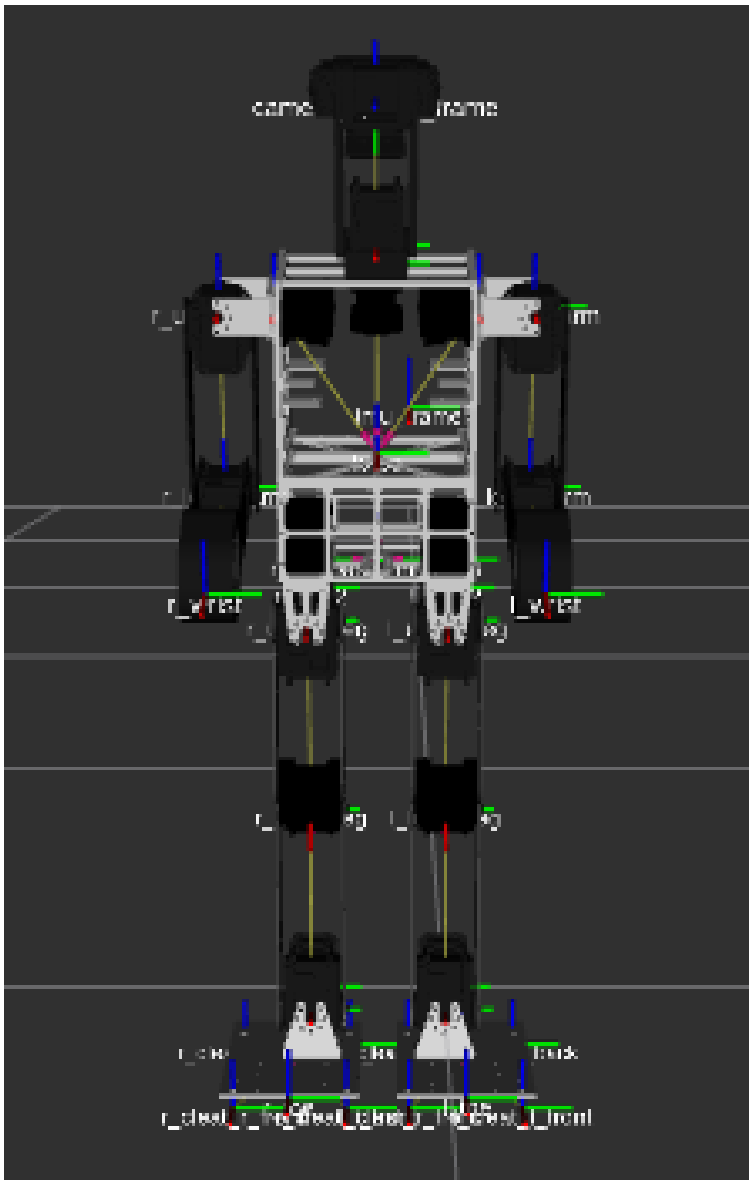
http://emanual.robotis.com/assets/images/dxl/mx/mx-106r_product.jpg

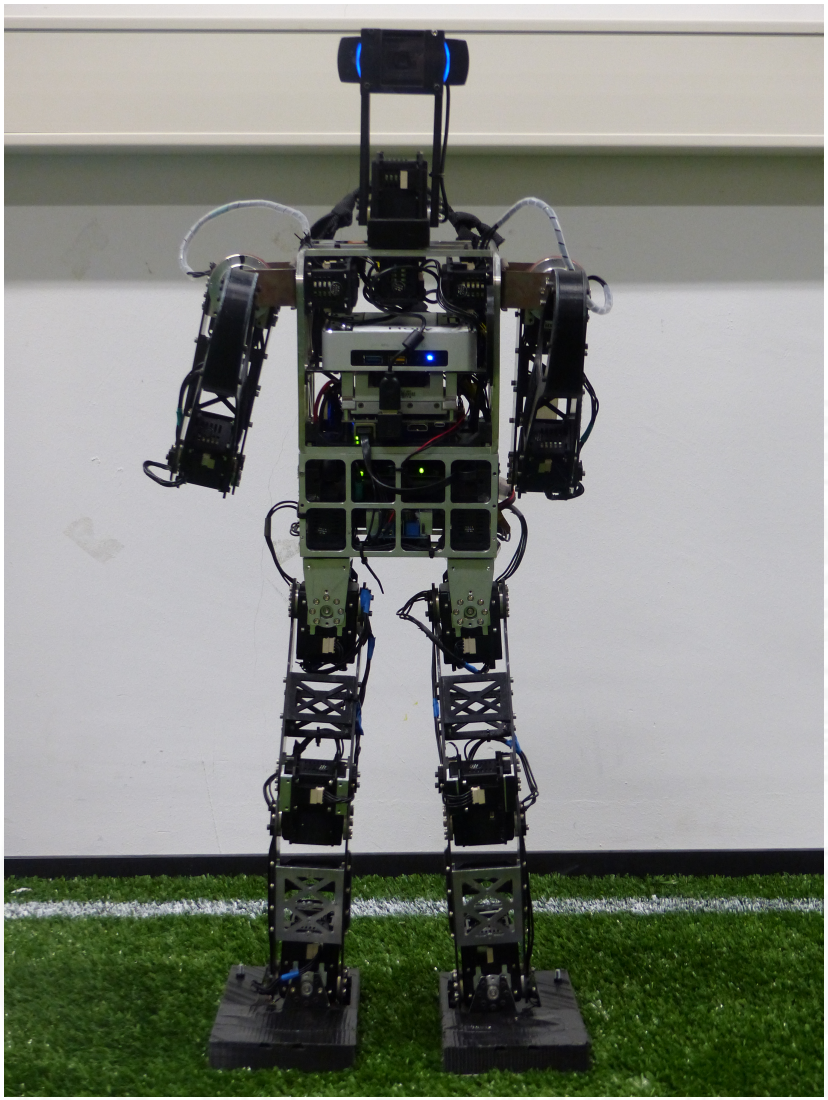
- servo motor
  - brushed DC Motor
  - Position Encoder and several other electronic components
  - Gearbox
- position control is used
- PID controller
- in the robot:
  - connected in parallel over bus system
  - MX 106 in the legs
  - MX 64 in arms and head

Influence of motor structure to robot's dynamics

- gear ratio
- backlash
- rotor inertia
- friction
- windings of coil

URDF

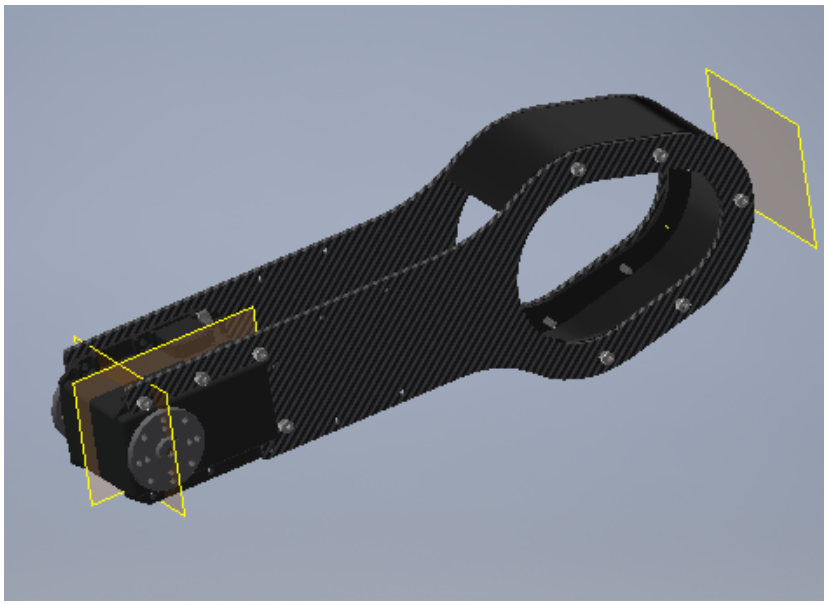


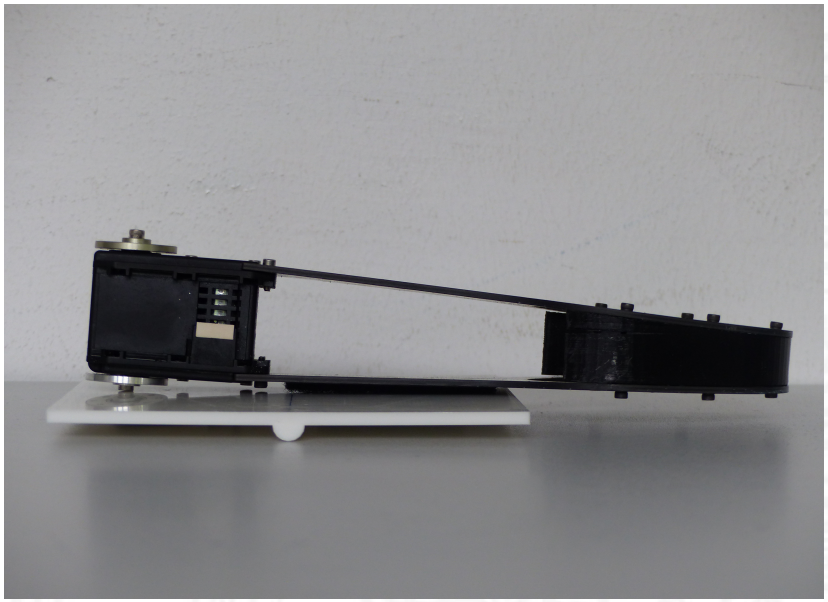


URDF Link element

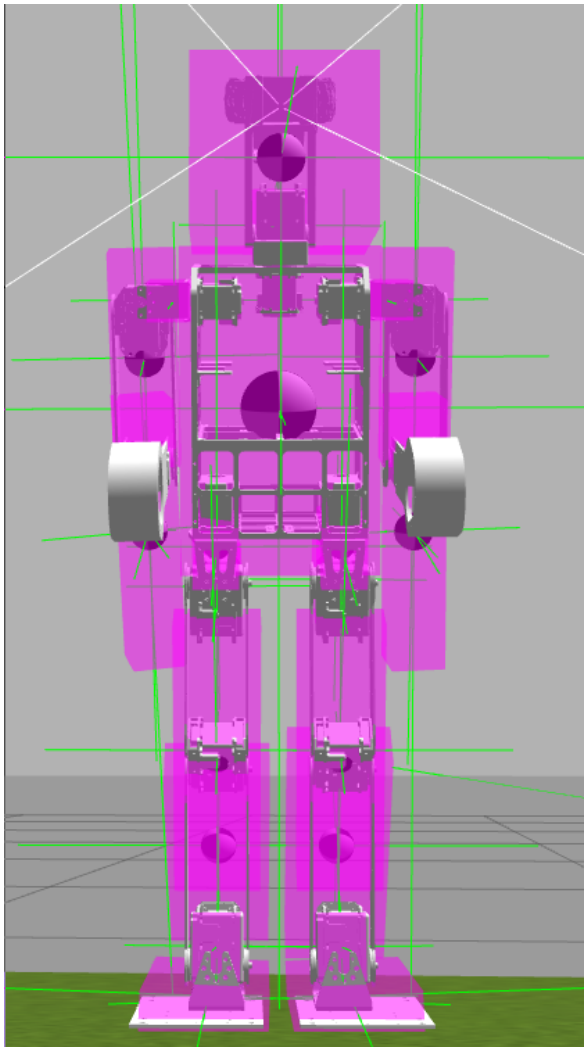

```
1  <link name="l_upper_arm">
2      <inertial>
3          <origin xyz="0.000158 -0.000012 -0.035495" rpy="0 0 0" />
4          <mass value="0.229" />
5          <inertia ixx="0.000490959" ixy="-0.000000004"
6                   ixz="-0.000004117" iyy="0.000461542"
7                   iyz="-0.000000191" izz="0.000102122" />
8      </inertial>
9      <visual>
10         ...
11     </visual>
12     <collision>
13         ...
14     </collision>
15 </link>
```

Update Inertial Parameters

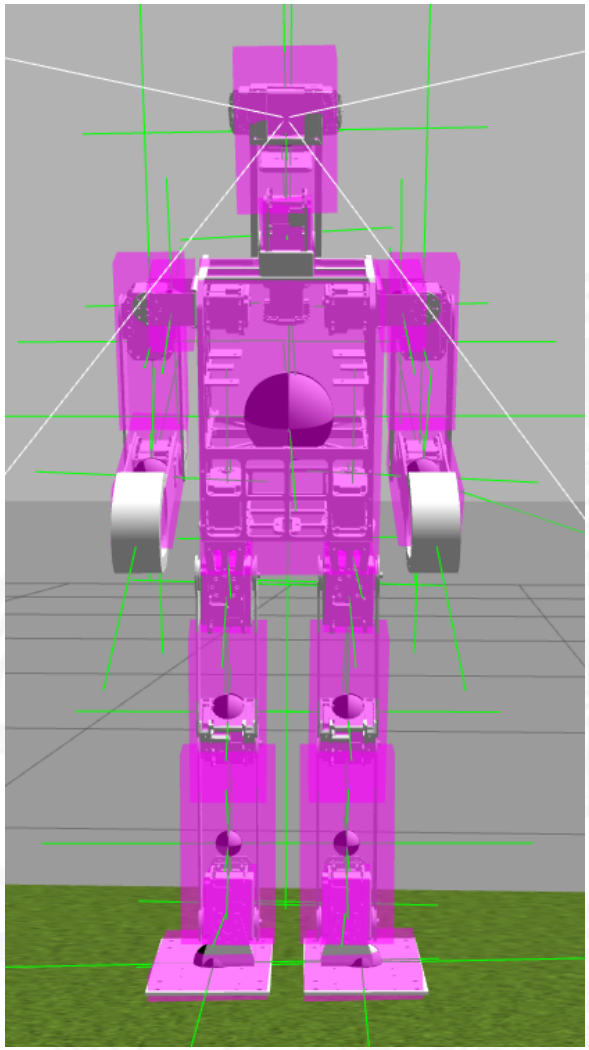




Inertial Parameters: Front View

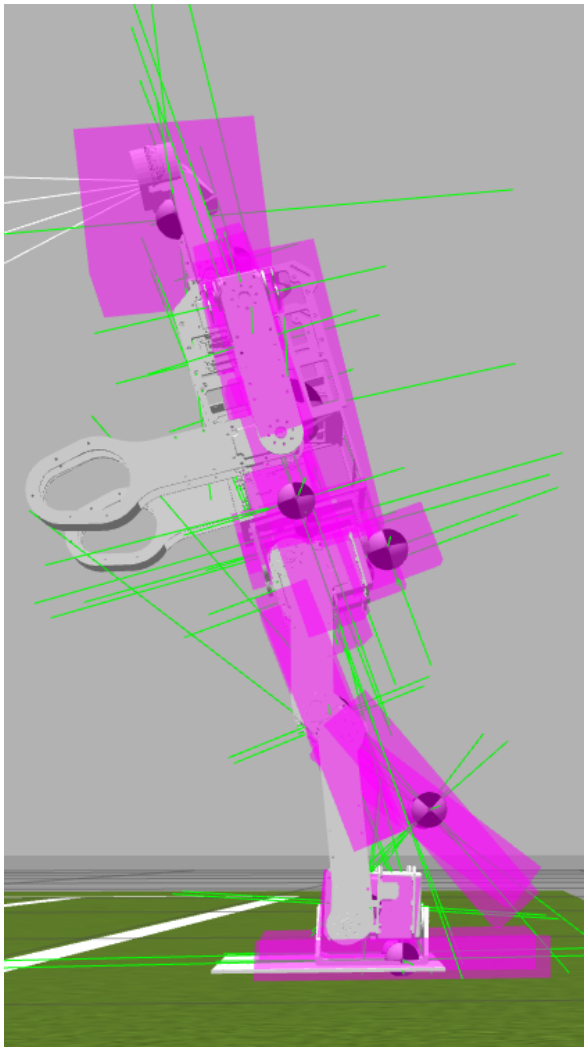


Before Update

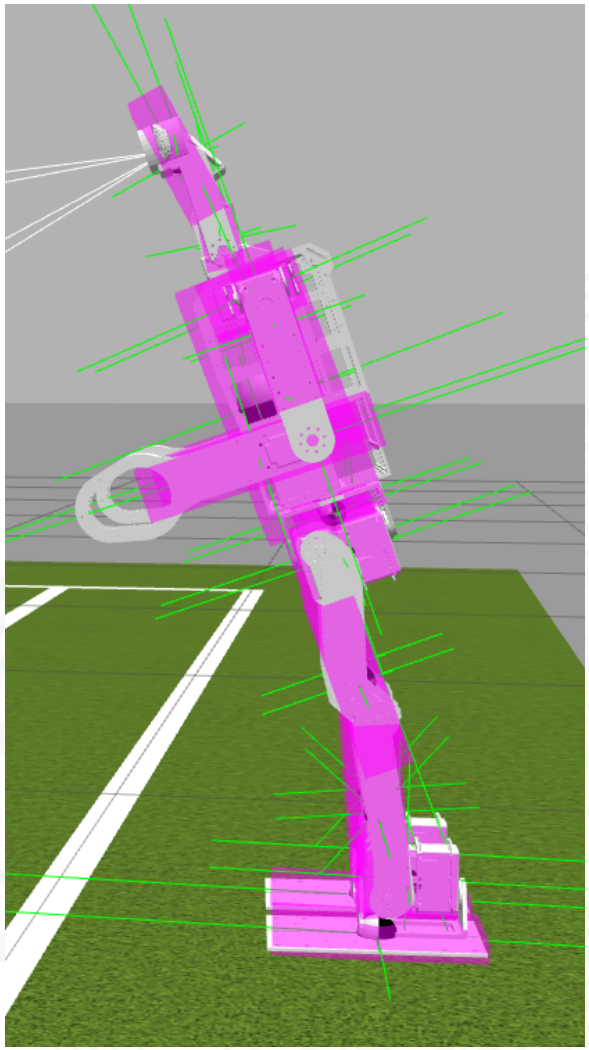


After Update

Inertial Parameters: Side View

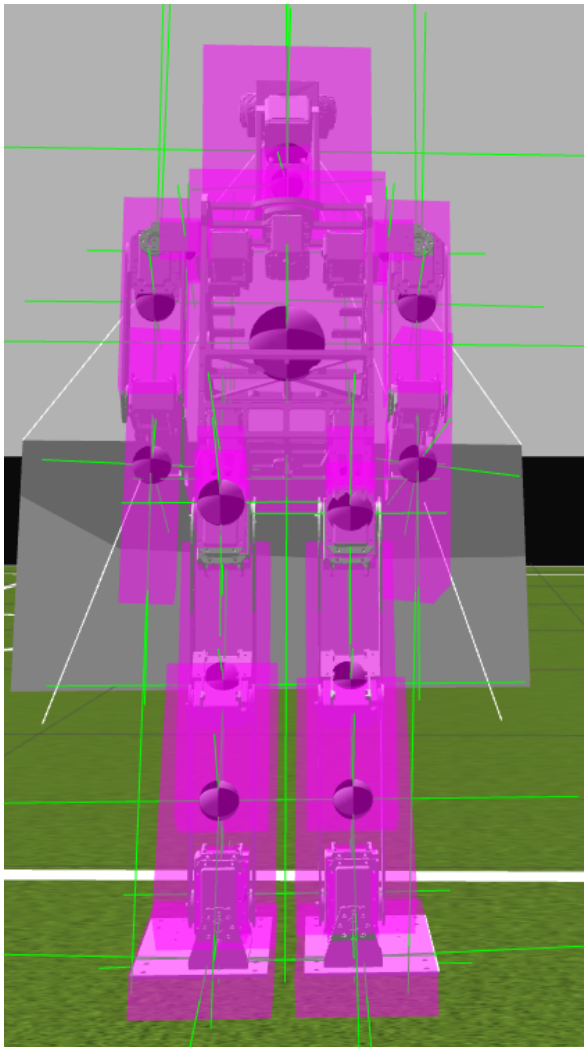


Before Update

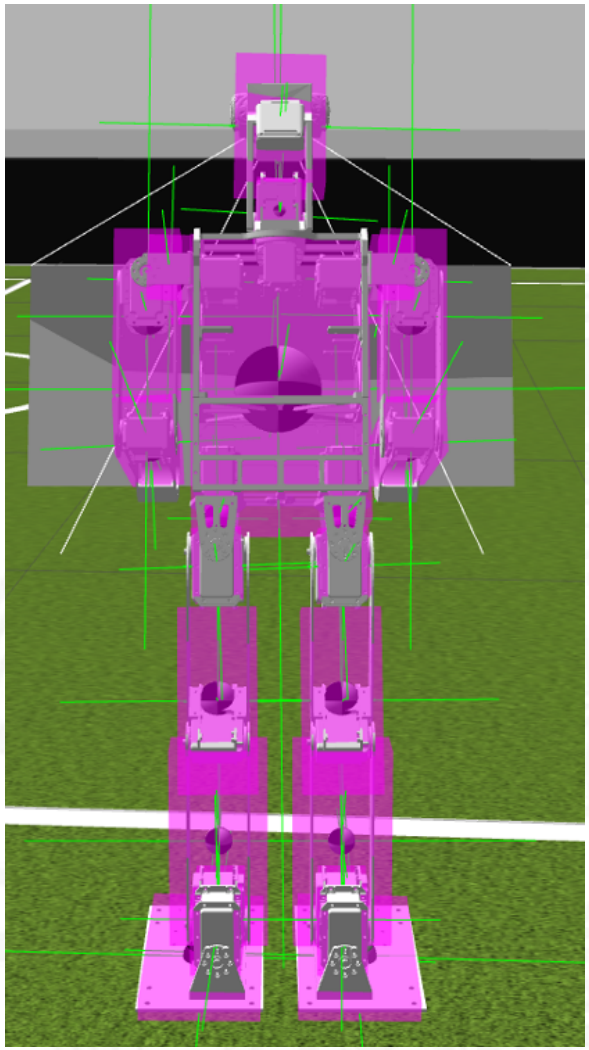


After Update

Inertial Parameters: Back View



Before Update



After Update

Update of mass values

- average difference: 23,9%
- maximum difference: 281% (Shoulder)
- minimum difference: 1,84% (Neck)
- 7/12 mass values differ about more than 30%

URDF Joint element


```
1 <joint name="RElbow" type="revolute">
2     <parent link="r_upper_arm" />
3     <child link="r_lower_arm" />
4     <limit effort="2.5" velocity="5.6548668" lower="-1.635"
5            upper="1.5707963267910001" />
6     <dynamics damping="1.0" friction="1.0" />
7 </joint>
```

Input Voltage - Why is it interesting?

- figuring out the input voltage of the robot's motors
- check the motor's return value
- $\omega = \frac{V}{k} - \frac{T}{k^2}R$

  ω angular velocity
  k torque constant of the motor
  T torque
  R coil resistance
  V voltage

Input Voltage - Observations

- Evaluation of the motor's feedback precision:

	motor accuracy	mean difference	maximum difference
hanging	± 0.1 V	0.14 V	0.31 V
standing	± 0.2 V	0.09 V	0.24 V
walking	± 0.3 V	0.24 V	0.6V

- Voltage decreases under load
- Leg chains experience higher voltage drop
- Input Voltage under accumulator usage:

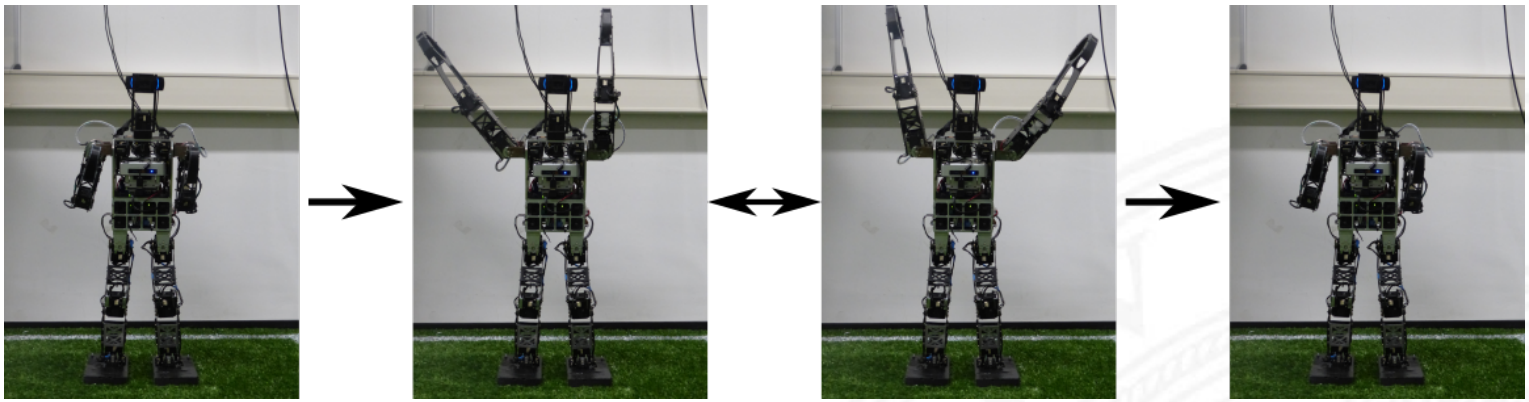
	MX 64	MX 106
maximum input voltage	16.0 V	15.8 V
minimum input voltage	12.8 V	12.7 V

Input Voltage - Results

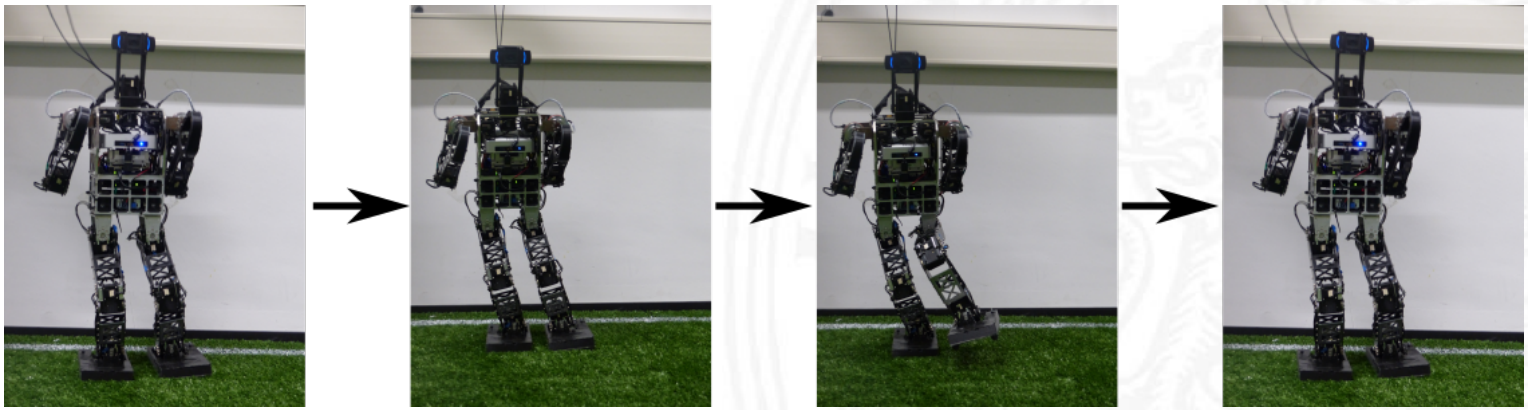
- accuracy of motor's feedback is quite different
- accuracy gets less precise with more load
- best results while medium load is acting on motors

Evaluation Concept

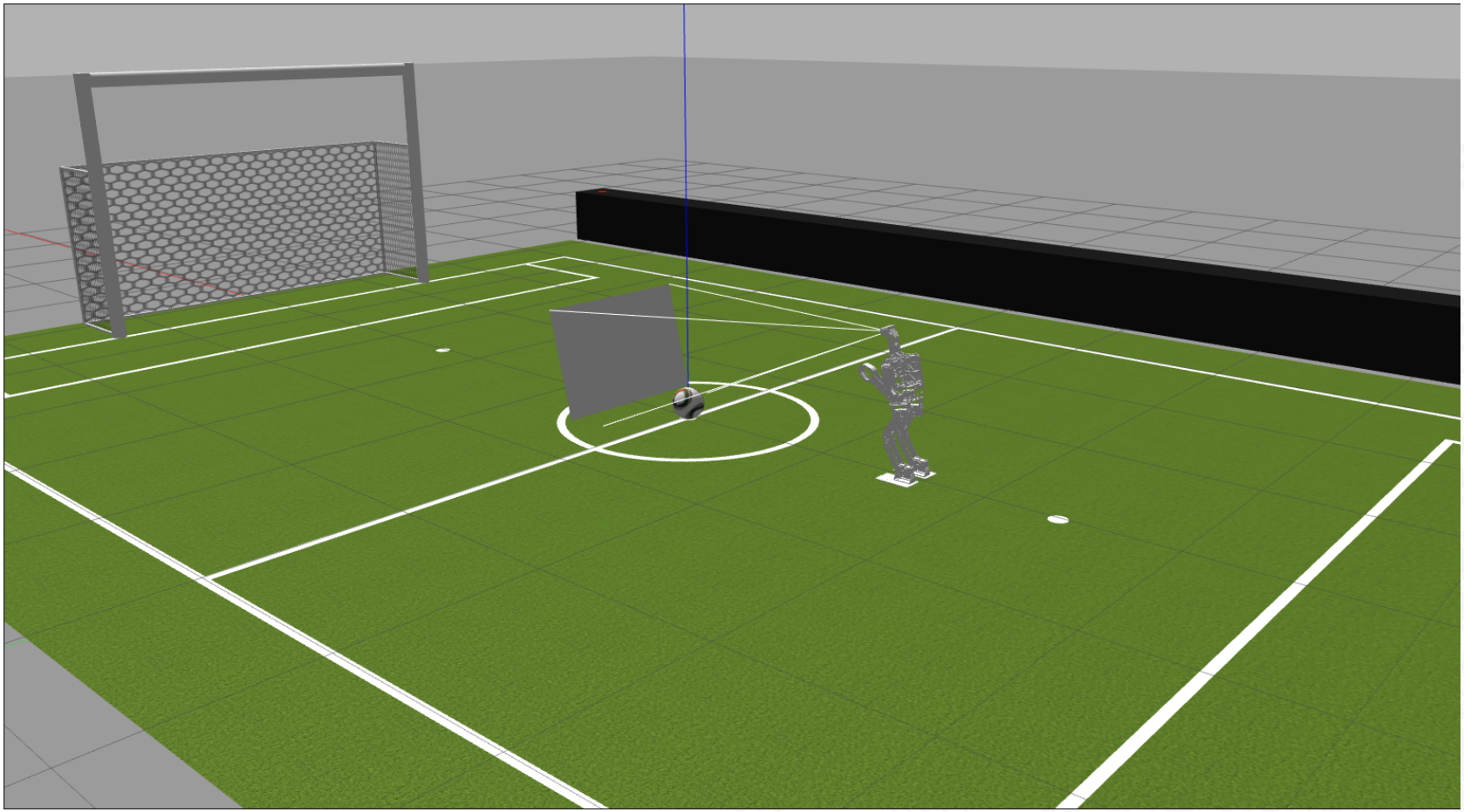
- Cheering



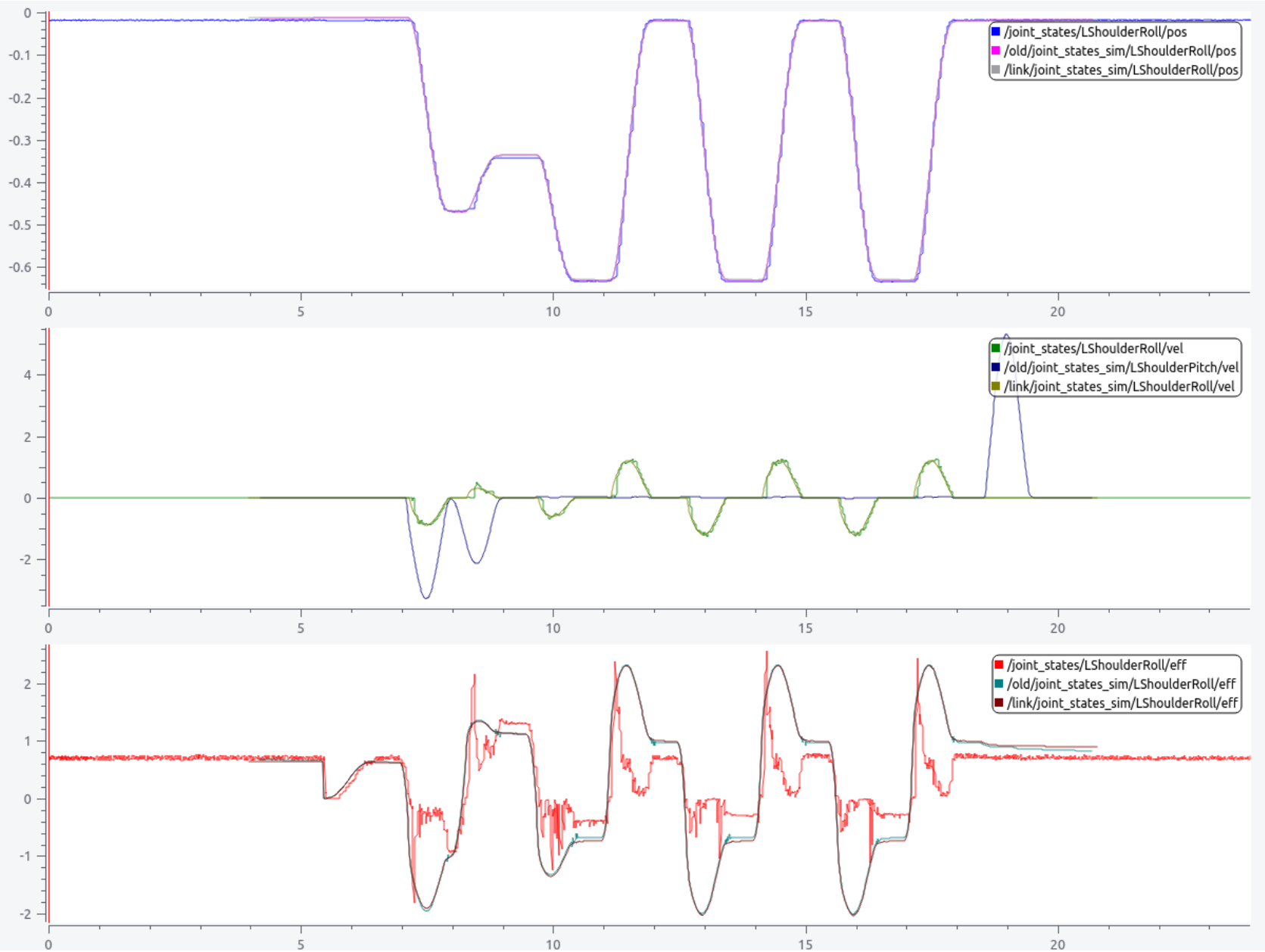
- Kicking



Gazebo



Cheering


/joint_states/LShoulderRoll/pos
/old/joint_states_sim/LShoulderRoll/pos
/link/joint_states_sim/LShoulderRoll/pos
/joint_states/LShoulderRoll/vel
/old/joint_states_sim/LShoulderPitch/vel
/link/joint_states_sim/LShoulderRoll/vel
/joint_states/LShoulderRoll/eff
/old/joint_states_sim/LShoulderRoll/eff
/link/joint_states_sim/LShoulderRoll/eff

Cheering (cont.)

Cheering: Sim/Real Difference of Moving Joints

Before Link Revision:

	position [°]	velocity[°/s]	effort[Nm]
mean	0.64219	0.43638	0.98631
max	18.23455	46.34601	2.62023
min	0.00025	1.96714e-15	3.27966e-05

After Link Revision:

	position [°]	velocity[°/s]	effort[Nm]
mean	0.55031	0.41562	0.95452
max	18.62994	47.73141	2.62734
min	1.59846e-05	5.15184e-15	9.49088e-05

Cheering: Sim/Real Difference of Not Moving Joints

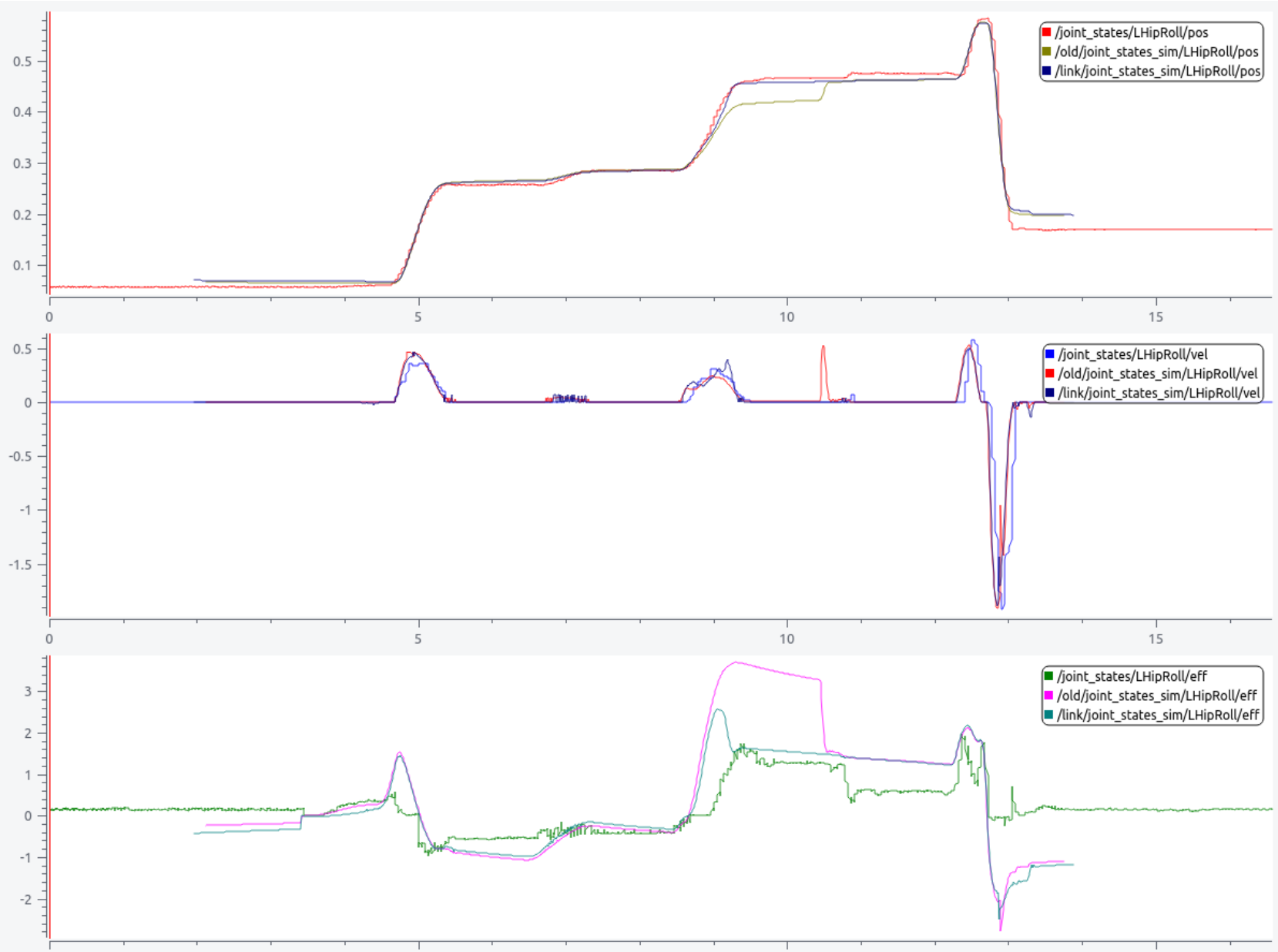
Before Link Revision:

	position [°]	velocity[°/s]	effort[Nm]
mean	1.00746	0.84387	0.04702
max	1.93486	12.08554	1.60676
min	0.00655	1.62175e-14	0.00035

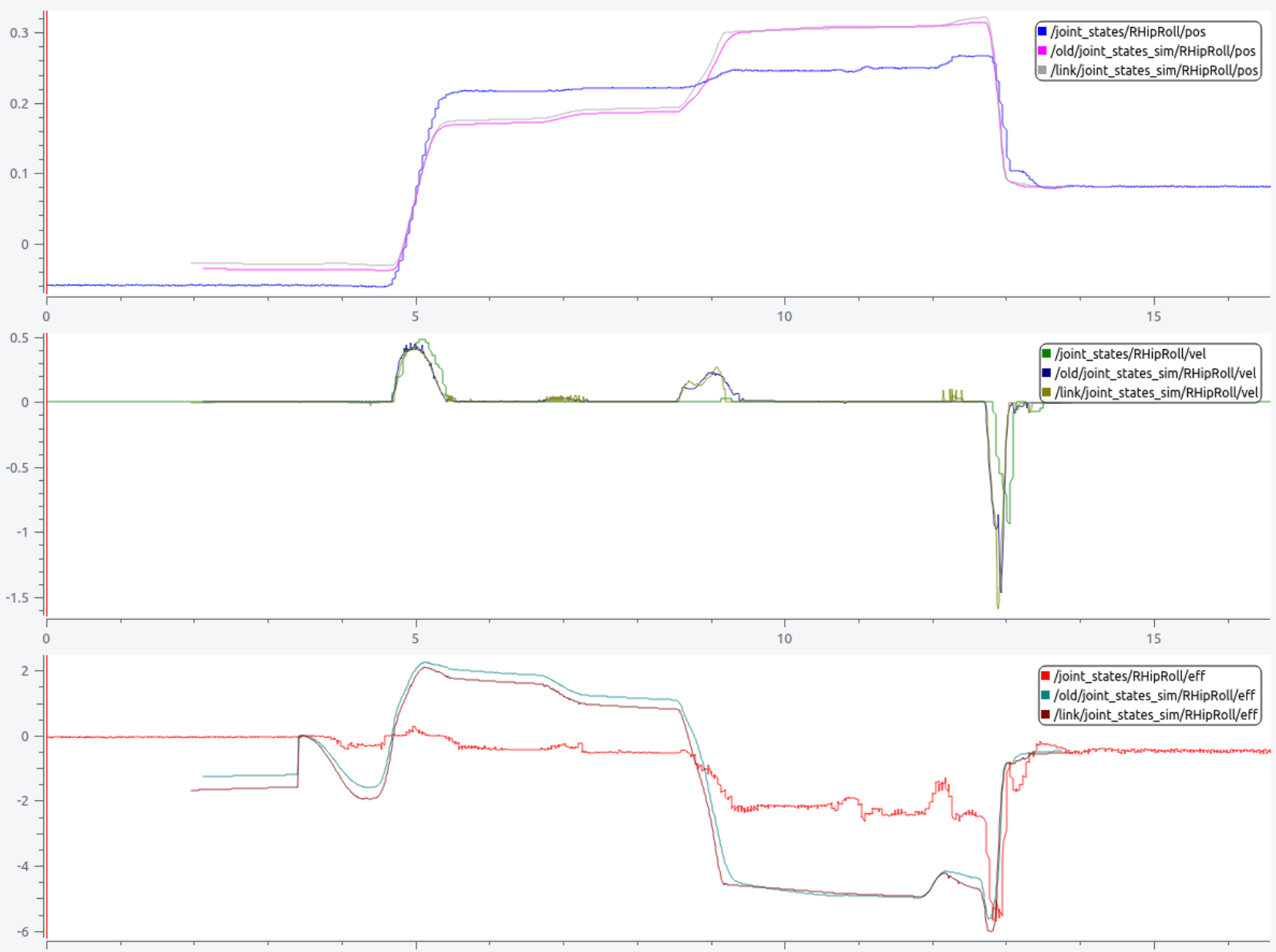
After Link Revision:

	position [°]	velocity[°/s]	effort[Nm]
mean	1.21111	1.03849	0.04282
max	3.03688	2.89502	2.69040
min	0.02196	2.07937e-14	0.05121

Kicking


/joint_states/LHipRoll/pos
/old/joint_states_sim/LHipRoll/pos
/link/joint_states_sim/LHipRoll/pos
/joint_states/LHipRoll/vel
/old/joint_states_sim/LHipRoll/vel
/link/joint_states_sim/LHipRoll/vel
/joint_states/LHipRoll/eff
/old/joint_states_sim/LHipRoll/eff
/link/joint_states_sim/LHipRoll/eff

Kicking (cont.)



Kicking: Sim/Real Difference of Moving Joints

Before Link Revision:

	position [°]	velocity[°/s]	effort[Nm]
mean	0.60783	0.52153	0.88032
max	2.50230	35.201648	2.46155
min	1.13761e-05	5.33492e-06	0.00023

After Link Revision:

	position [°]	velocity[°/s]	effort[Nm]
mean	0.82639	0.72827	0.74973
max	4.18295	34.52876	3.75501
min	1.051425e-06	1.95752e-06	7.33297e-06

Kicking: Sim/Real Difference of Not Moving Joints

Before Link Revision:

	position [°]	velocity[°/s]	effort[Nm]
mean	0.66931	0.54698	0.07613
max	1.82544	5.95516	1.42683
min	0.00474	1.64308e-15	6.271545e-06

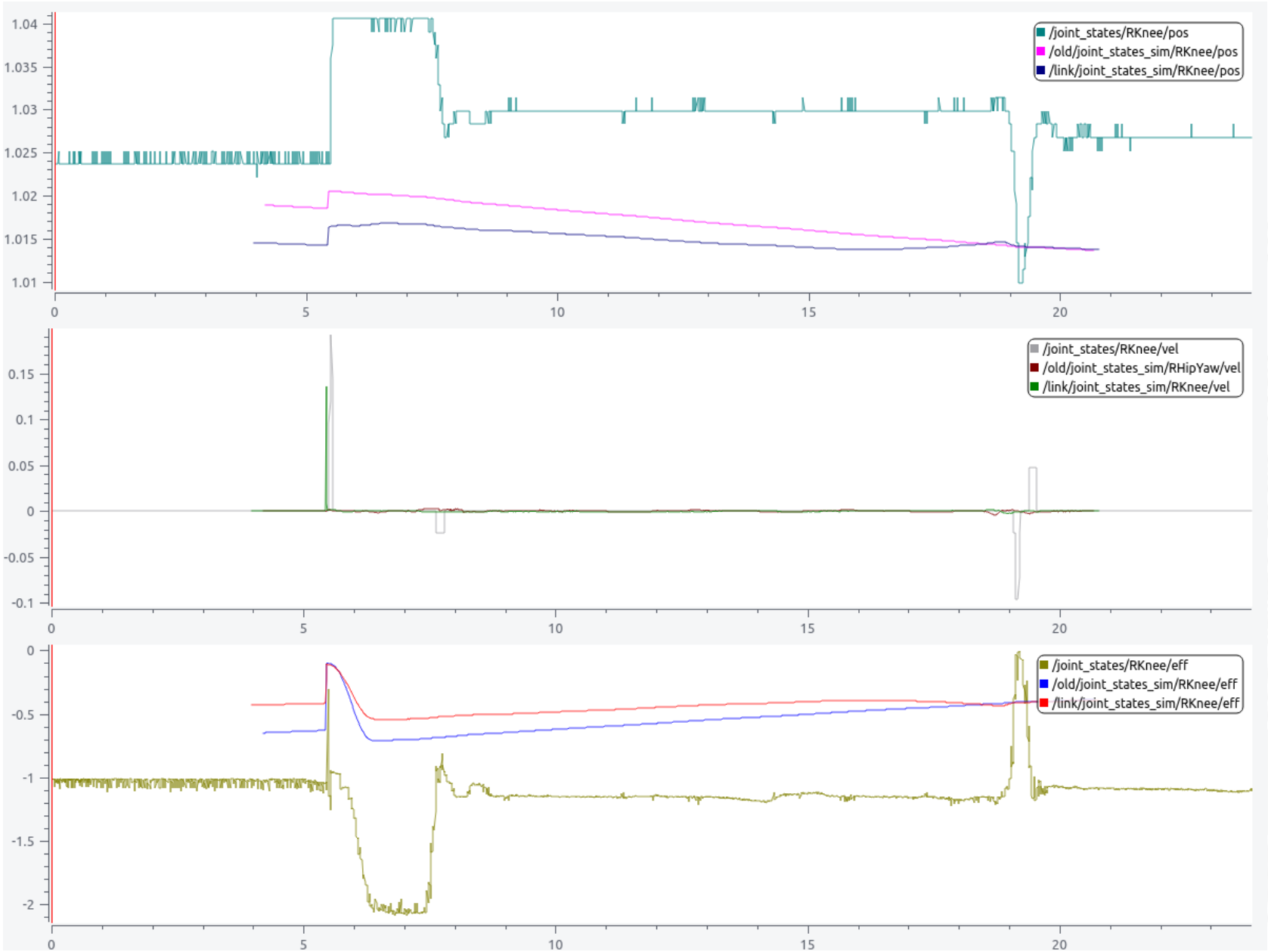
After Link Revision:

	position [°]	velocity[°/s]	effort[Nm]
mean	0.46166	0.40183	0.04714
max	1.21124	5.95520	0.89038
min	0.05262	1.59625e-13	7.062484e-06

Conclusion

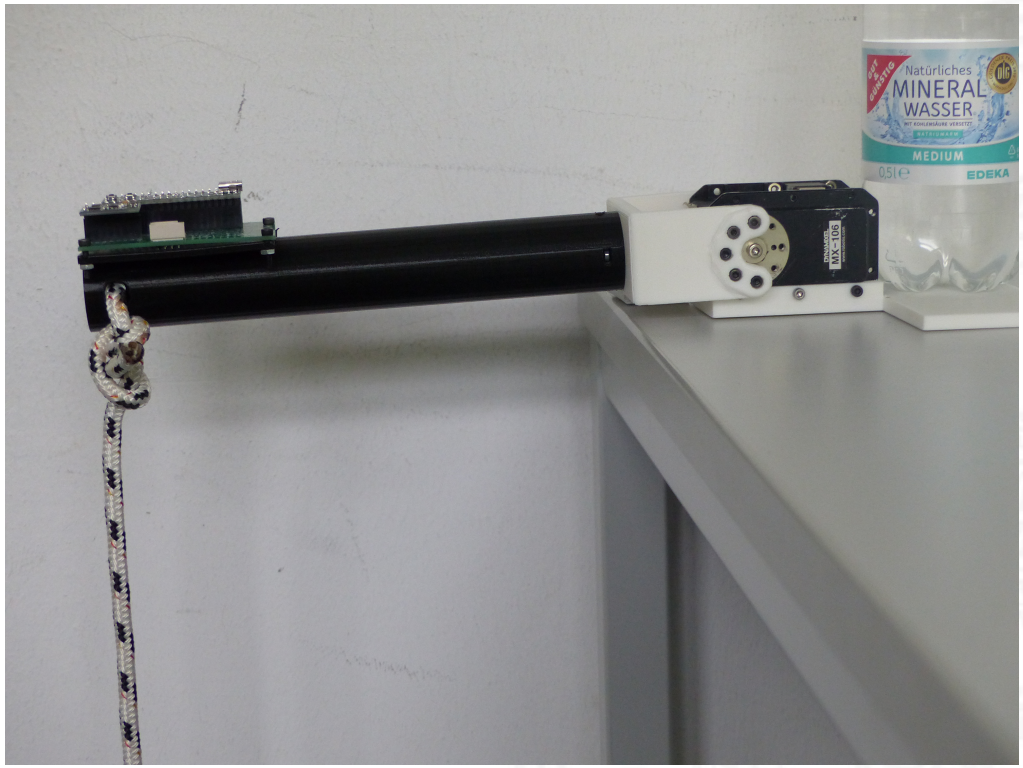
- mean got better or just slightly worse ($<$ backlash)
- simulation of arm joints is improved
- for moving joints still too high maximum differences
- viewable behavior in Gazebo is more realistic
- simulation is more balanced

Conclusion (cont.)



Next steps

- measurement of motor's torque
- measurement of the motor's static friction



Future Work

- Adaptions due to changes in robot's hardware
- Analysis of forces
- Analysis of temperature impact
- Precise Input Voltage Analysis
- Plugin for Gazebo to simulate actuator
  - consider motor characteristics
  - adaption to different loads
  - simulate battery operation

Thank you for your attention.
Do you have any questions?