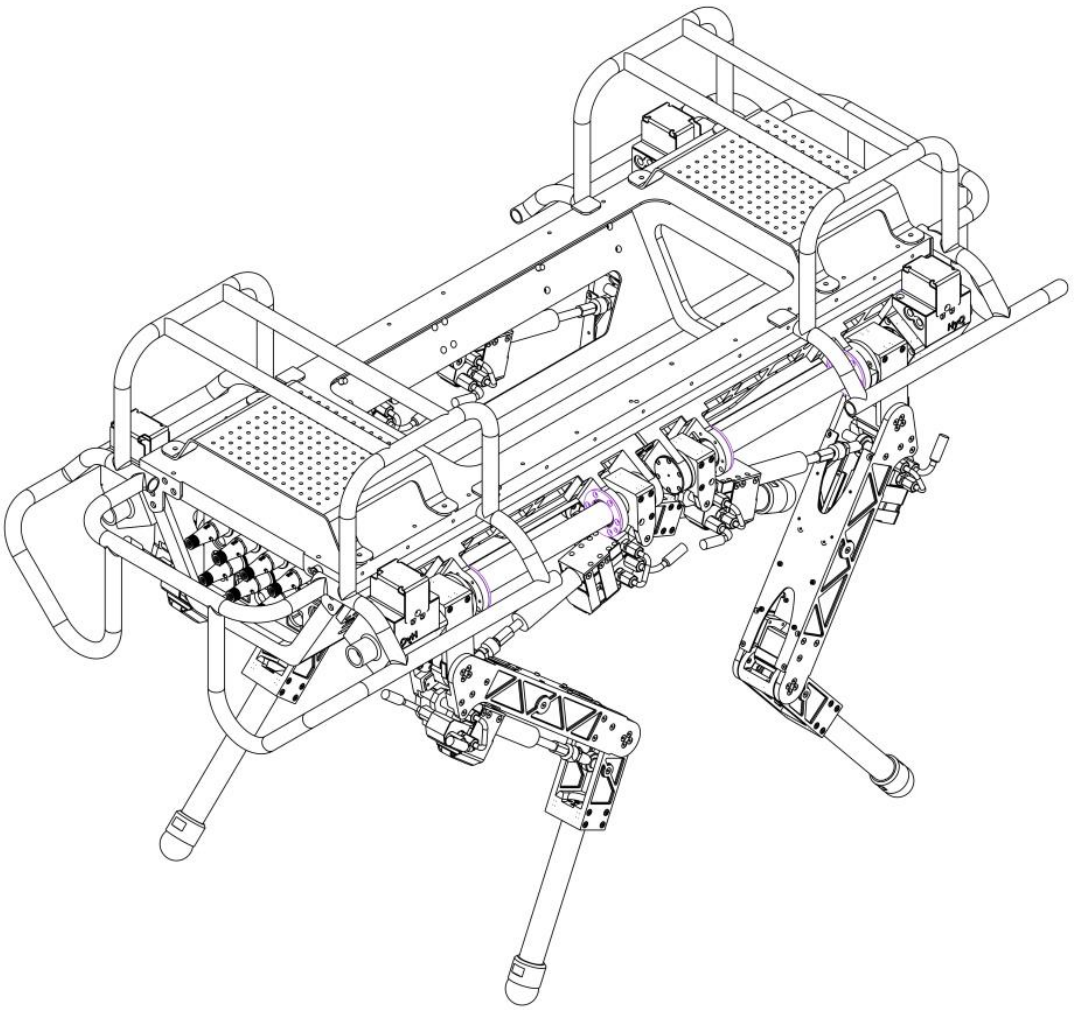
HyQ-Robot:
Standard Definition for Joint Angles and Kinematic Parameters of the Legs and Torso



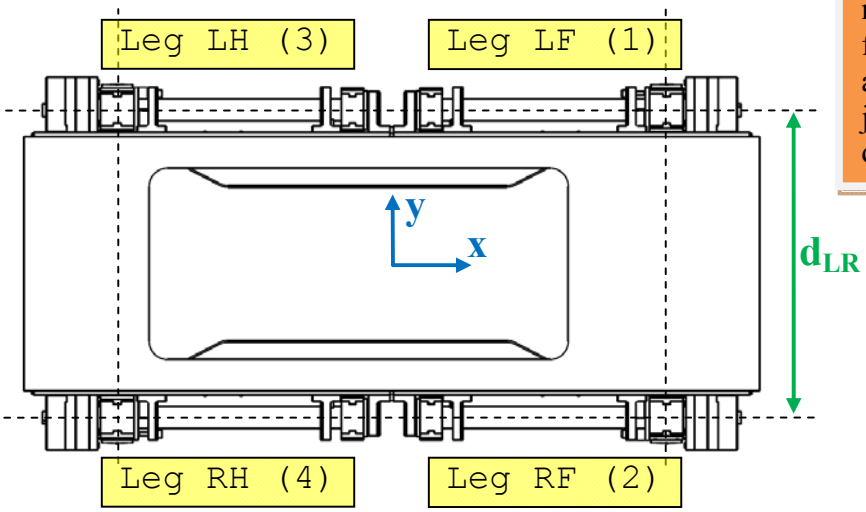
Document Version 4.0

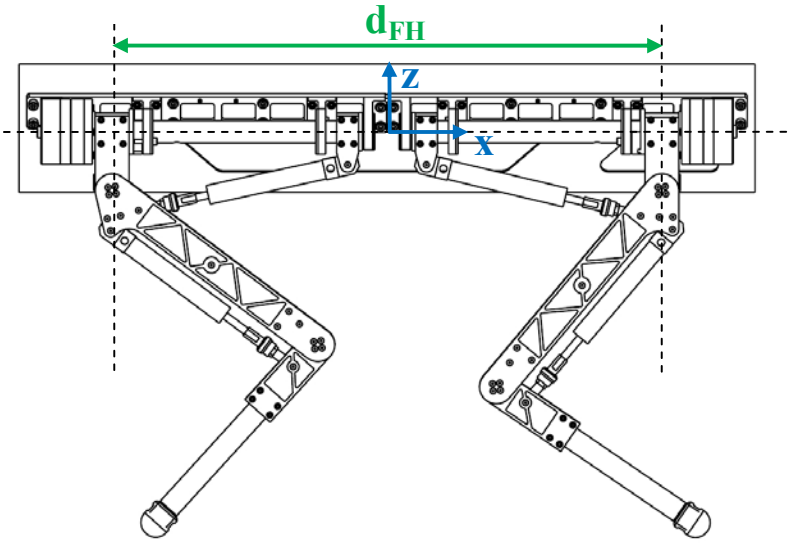
February 2017

Leg Nomenclature, Location on Torso and Robot Base Coordinate Frame

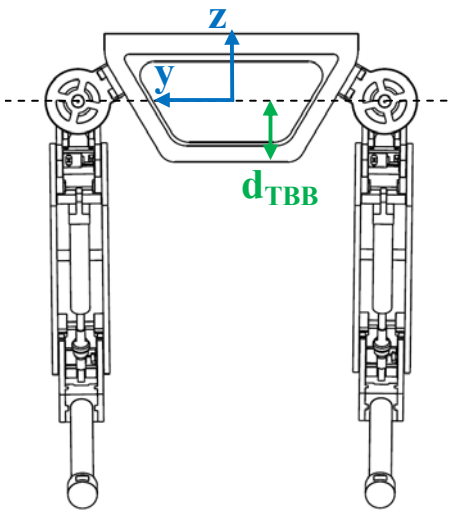
Note that most robot drawings show HyQ in its 2010 version. In the meantime, the HAA actuator and foot have been upgraded. The affected kinematic parameters and joint limits have been updated in this document and marked in red.

top view





side view



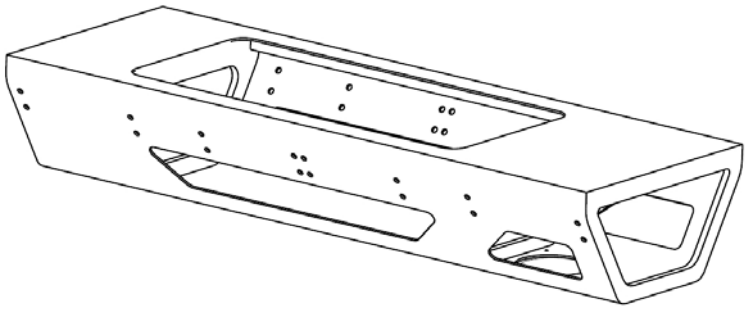
back view

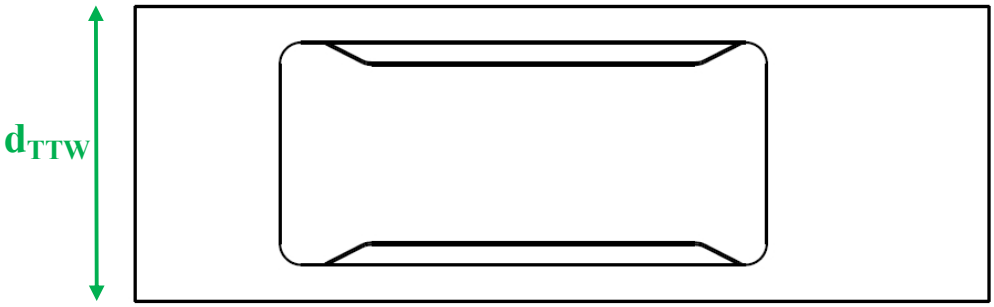
d_{LR} = 0.414 m (left to right)
d_{FH} = 0.747 m (front to hind)
d_{TBB} = 0.085 m (torso bottom to base coordinate frame) [measured on torso]

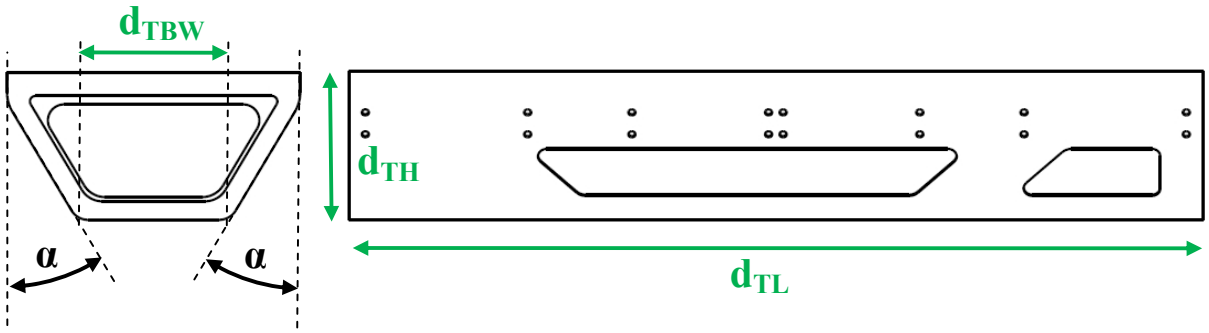
Leg 1: Left Front (LF)
Leg 2: Right Front (RF)
Leg 3: Left Hind (LH)
Leg 4: Right Hind (RH)

Definition of *hind*:
located at or forming the back or rear
e.g. an animal's hind legs

Dimensions/Mass of Robot Torso

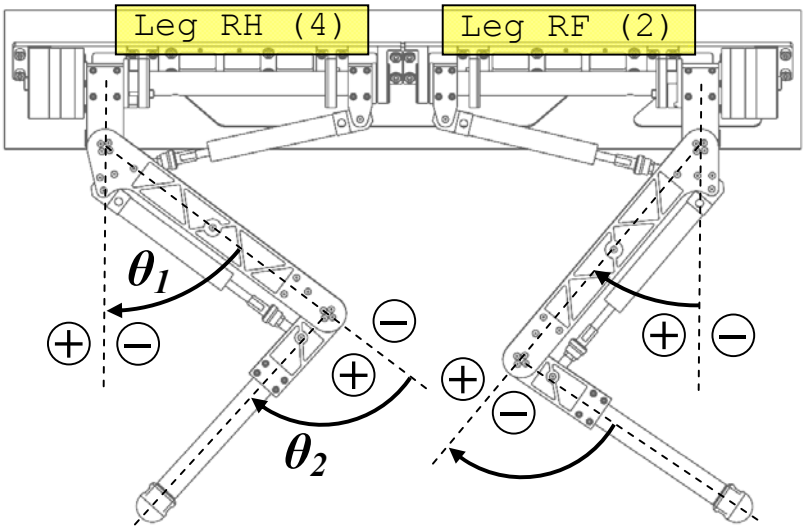






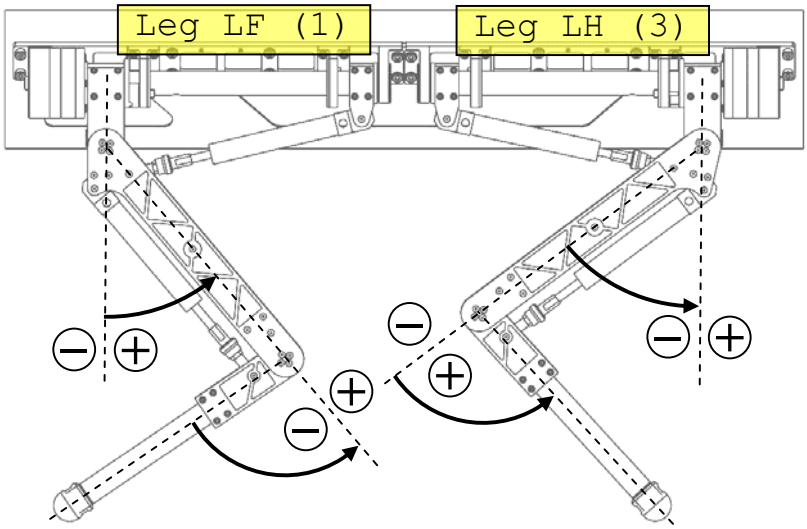
d_{TL} = 1.0 m	(torso length)	
d_{TH} = 0.18 m	(torso height)	[measured on torso]
d_{TTW} = 0.34 m	(torso top width)	
d_{TBW} = 0.18 m	(torso bottom width)	
α = 30°		
m_{TORSO} = 10.0 kg		

Definition of Joint Angles and Range of Motion



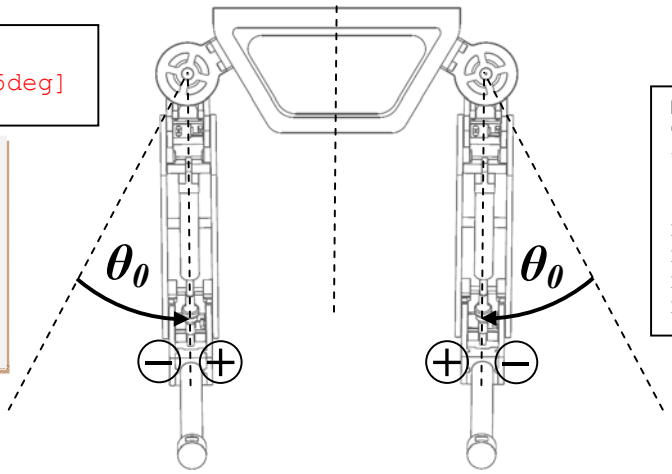
Leg RH (4):
θ_1 = [-70deg .. +50deg]
θ_2 = [+20deg .. +140deg]

Leg RF (2):
θ_1 = [-50deg .. +70deg]
θ_2 = [-140deg .. -20deg]



Leg LF (1):
θ_1 = [-50deg .. +70deg]
θ_2 = [-140deg .. -20deg]

Leg LH (3):
θ_1 = [-70deg .. +50deg]
θ_2 = [+20deg .. +140deg]



all legs:
θ_0 = [-70deg .. +25deg]

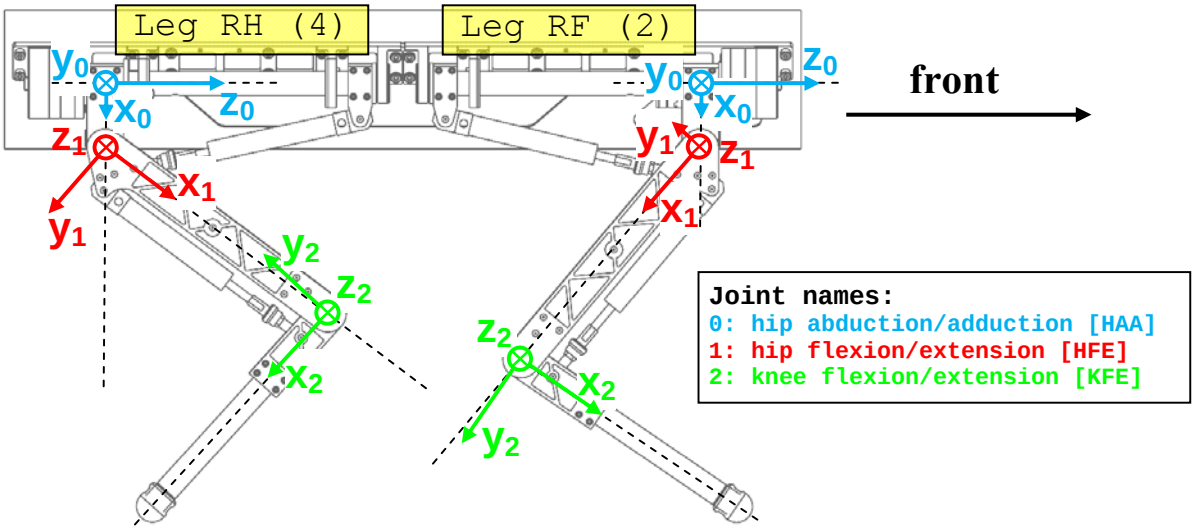
The hydraulic vane motors have less range, so this was update in doc version 3.0

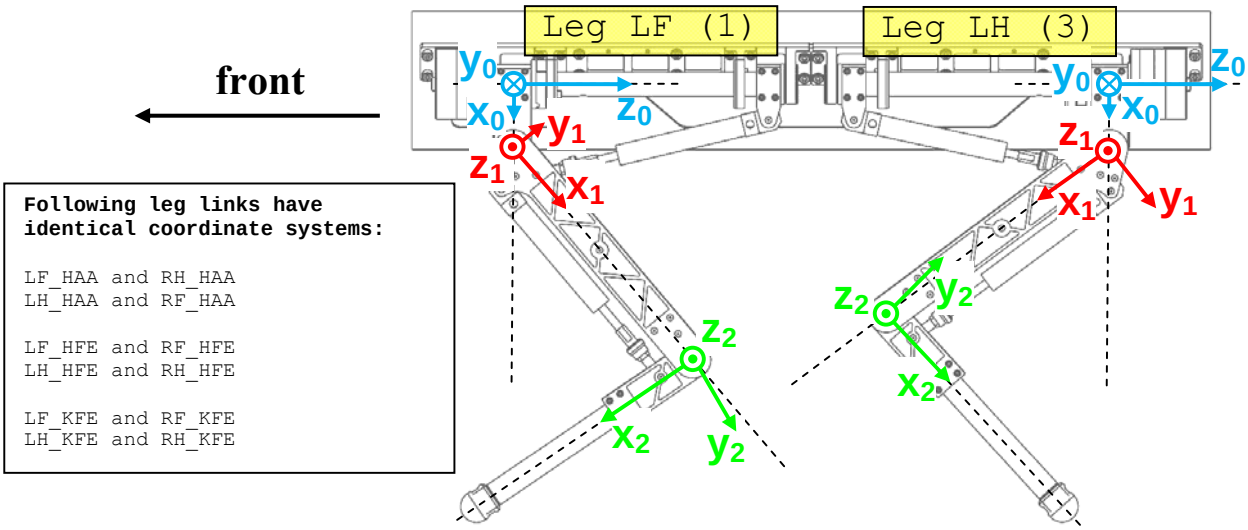
Example
The shown posture has the following angles:
(with $\theta=[\theta_0,\theta_1,\theta_2]$)

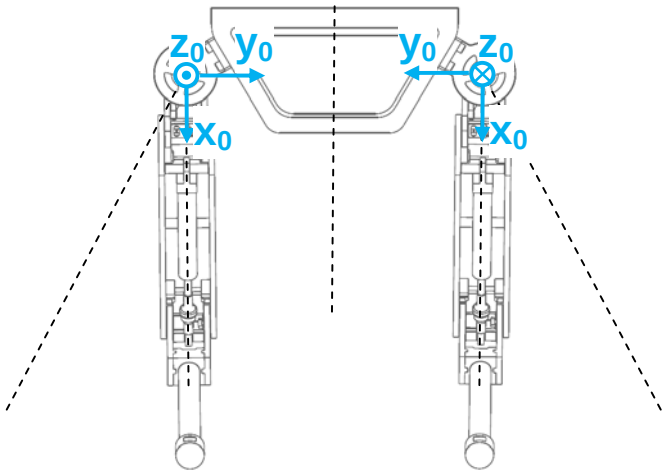
Leg LF: $\theta=[0, 40deg, -96deg]$
Leg RF: $\theta=[0, 40deg, -96deg]$
Leg LH: $\theta=[0, -53deg, 95deg]$
Leg RH: $\theta=[0, -53deg, 95deg]$

All angles are mirrored in the plane that splits the robot into an identical left and right half (sagittal plane). Therefore, both front legs (LF,RF) and both hind legs (LH,RH) have the same range of motion and definition of angles.

Definition of Link Coordinate Systems and Joint Names

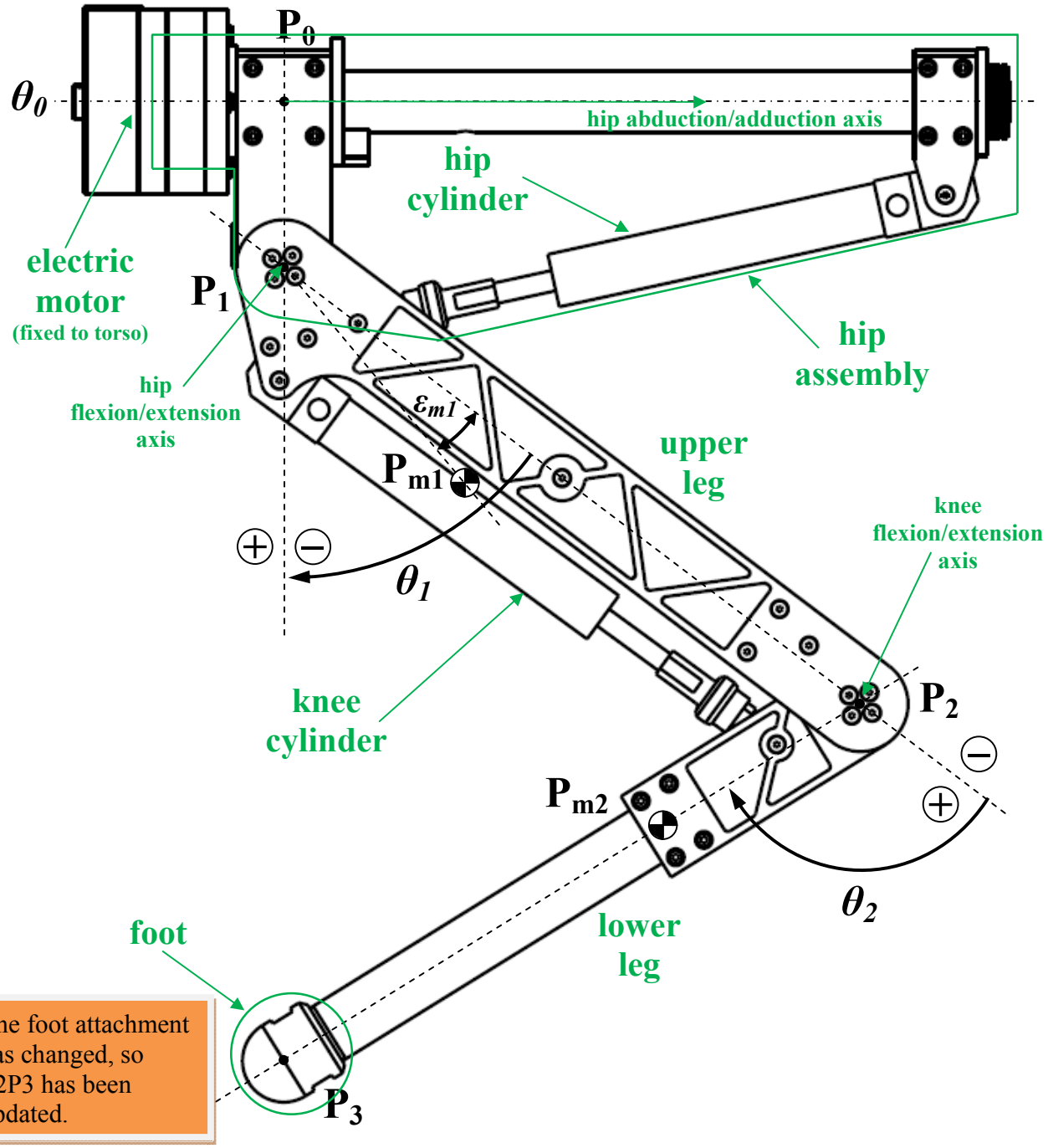






front/back view

Leg Mass/Inertia, Range of Motion of RH-Leg

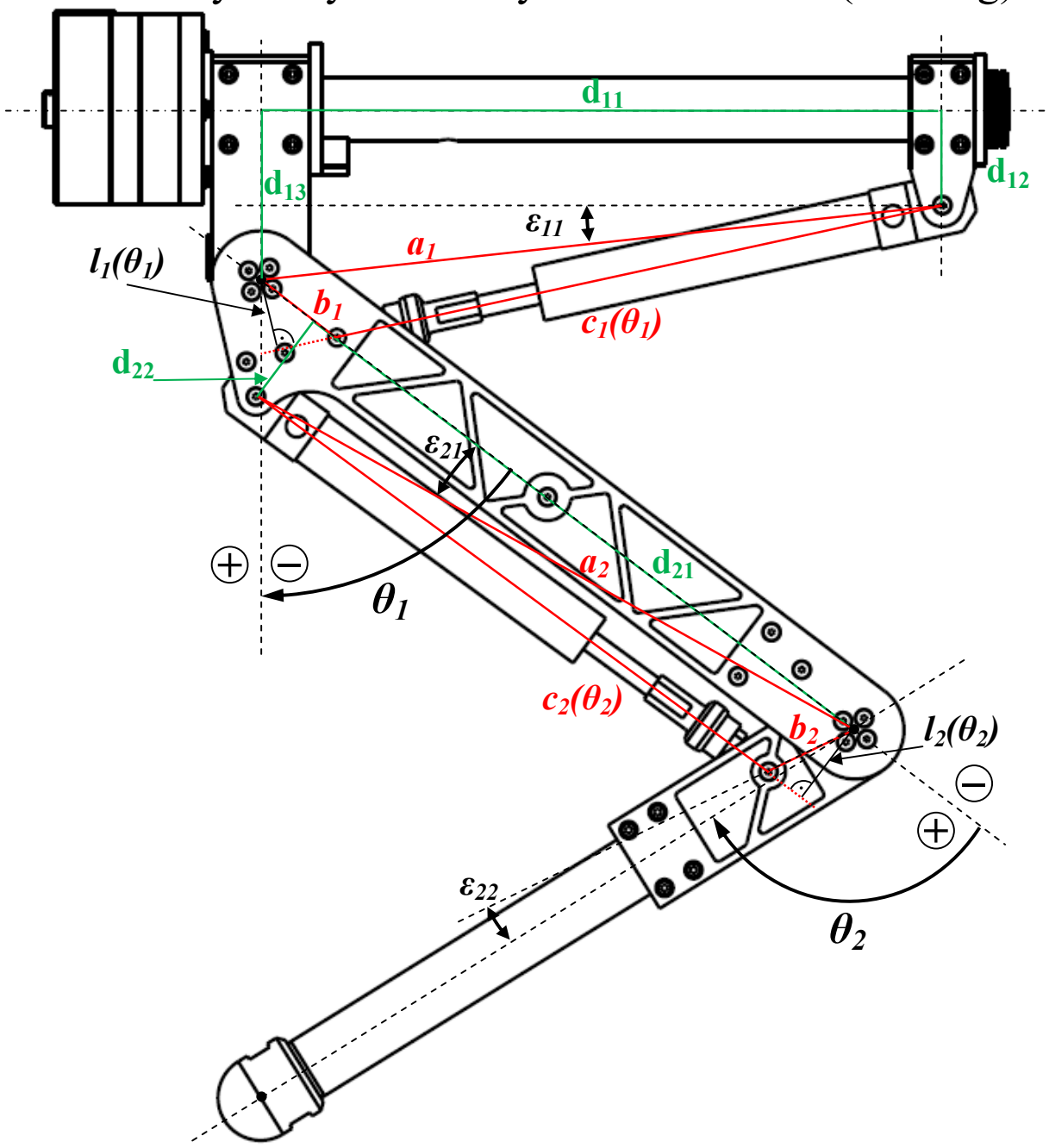


The foot attachment has changed, so P2P3 has been updated.

P_0P_1 = 0.08 m P_1P_2 = 0.35 m P_1P_{m1} = 0.164 m = sqrt(0.162^2+0.0225^2) ε_{m1} = 7.9 deg = atan(0.0225/0.162) Range of motion of θ_1=[-70deg..+50deg]	P_2P_3 = 0.346 m (foot radius: 0.02 m) P_2P_{m2} = 0.122 m [0.103 m without foot] (ε_{m2} = 0 deg) Range of motion of θ_2 =[+20deg..+140deg]

For updated mass and inertia properties of the leg segments and torso, please refer to the separate inertia properties document.

Geometry of Hydraulically Actuated Joints (RH-Leg)



$a_1 = 0.3219\ m = \sqrt{d_{11}^2+(d_{13}-d_{12})^2}$
$b_1 = 0.045\ m$
$\varepsilon_{11} = 6.24\ deg = \tan((d_{13}-d_{12})/d_{11})$
$(\varepsilon_{12} = 0\ deg)$
$c_1(\theta_1) = \sqrt{a_1^2 + b_1^2 - 2 a_1 b_1 \cos(\pi/2+\theta_1+\varepsilon_{11})}$
$l_1(\theta_1) = a_1 \sin(\arccos((a_1^2+c_1(\theta_1)^2-b_1^2)/(2 a_1 c_1(\theta_1))))$

$d_{11} = 0.32\ m$
$d_{12} = 0.045\ m$
$d_{13} = 0.08\ m$

$a_2 = 0.3218\ m = \sqrt{d_{21}^2+d_{22}^2}$
$b_2 = 0.045\ m$
$\varepsilon_{21} = 8.04\ deg = \tan(d_{22}/d_{21})$
$\varepsilon_{22} = 6.0\ deg$
$c_2(\theta_2) = \sqrt{a_2^2 + b_2^2 - 2 a_2 b_2 \cos(\pi-\theta_2-\varepsilon_{21}-\varepsilon_{22})}$
$l_2(\theta_2) = a_2 \sin(\arccos((a_2^2+c_2(\theta_2)^2-b_2^2)/(2 a_2 c_2(\theta_2))))$

$d_{21} = 0.3186\ m$
$d_{22} = 0.045\ m$

Document Revision History:

version	date	author	changes/comments
V1.0	01/2010	Semini	initial version.
V2.0	9/7/2010	Semini	added one page with definition of link coordinate systems, and added the labels to define *upper leg* and *lower leg*.
V3.0	4/12/2015	Semini	Since 2010, the HAA actuator and foot have been upgraded. The affected kinematic parameters and joint limits have been updated in this version and marked in red. Additionally, the torso height was corrected.
V4.0	23/2/2017	Semini	The lower leg length P2P3 is 5mm longer due to the new foot sensors. Only page 6 was affected: P_2P_3 = 0.346 m (previously 0.341 m)