Control & Teleoperation for a DARPA Robotics Challenge Humanoid Robot

Drexel University · University of Delaware · The Ohio State University · KAIST · Georgia Tech · Swarthmore · WPI · Indiana University · Purdue University · Columbia University

Core Team: 5 people

Debris removal

Wall breaking

Door opening

Today's Presentation

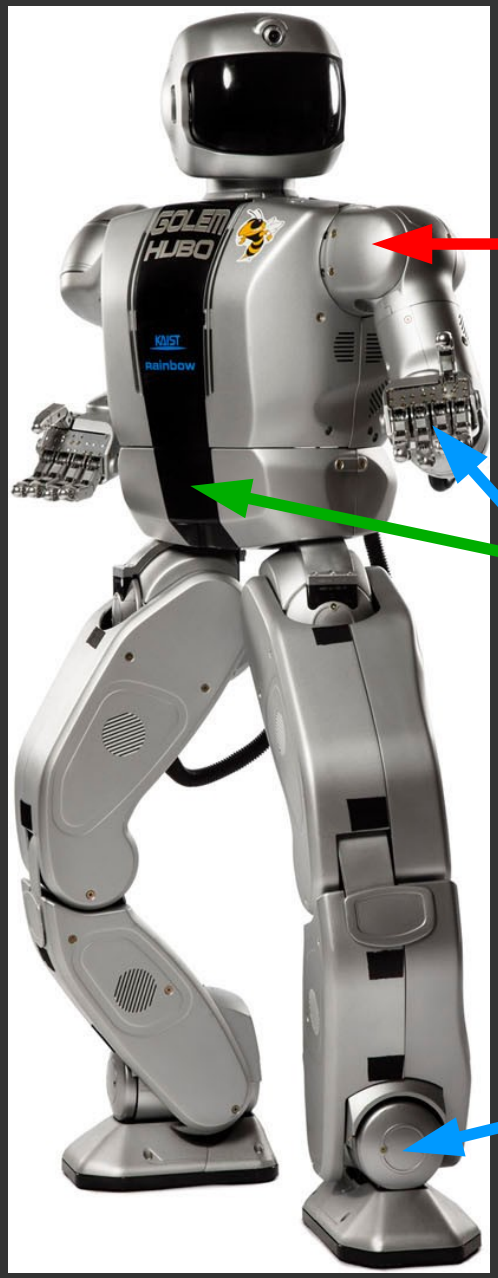
Start to Critical Design Review (CDR)

- HUBO2+
- Low-level Software
- Control and Teleoperation
- Walking
- Results

CDR to Semi-Finals

- DRC-HUBO
- Walking
- Operation Scheme
- Lessons Learned
- What Went Well

HUBO2+



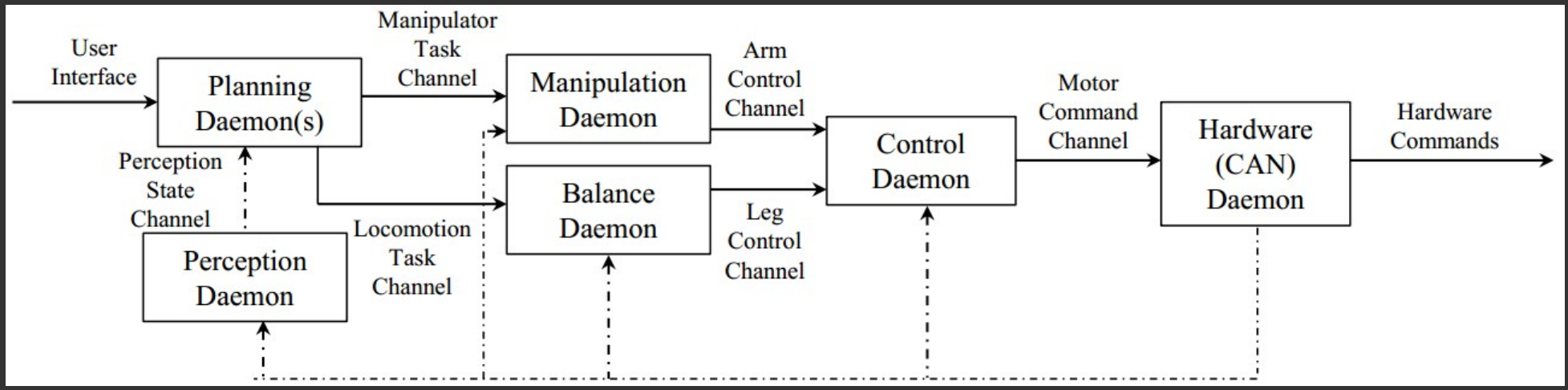
37 DoFs
CAN
Position Control

3-axis IMU

3-axis F/T
sensors

Real-time Architecture

Ach: IPC for Real-time control of robots[1]
Achd: TCP/UDP communication
Daemons: Background processes

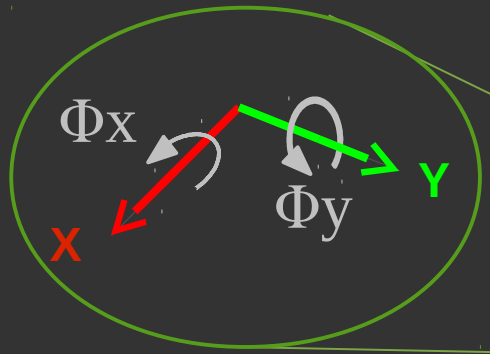


Major Contributions: Joint info parsing, balancing, walking daemon, UI

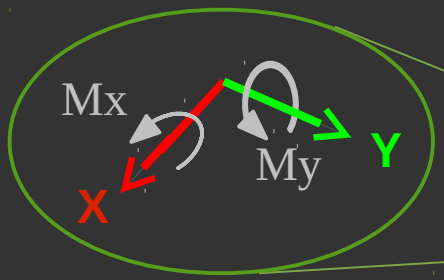
[1] N. Dantam and M.Stilman. Robust and efficient Communication for real-time multi-process robot software. International Conference on Humanoid Robotics (Humanoids). 2012.

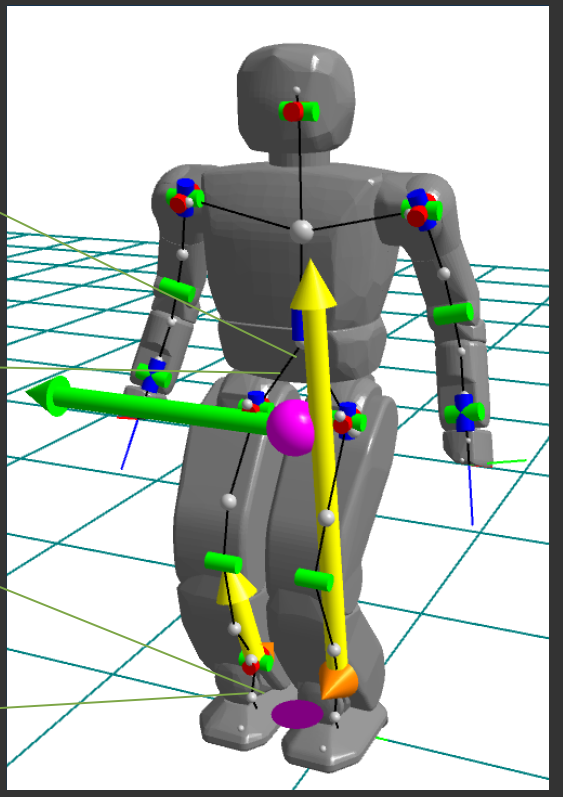
Balancing

Resist IMU



Comply with Moments





Balancing

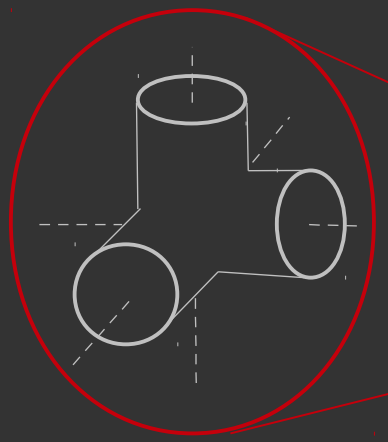
Kinematics

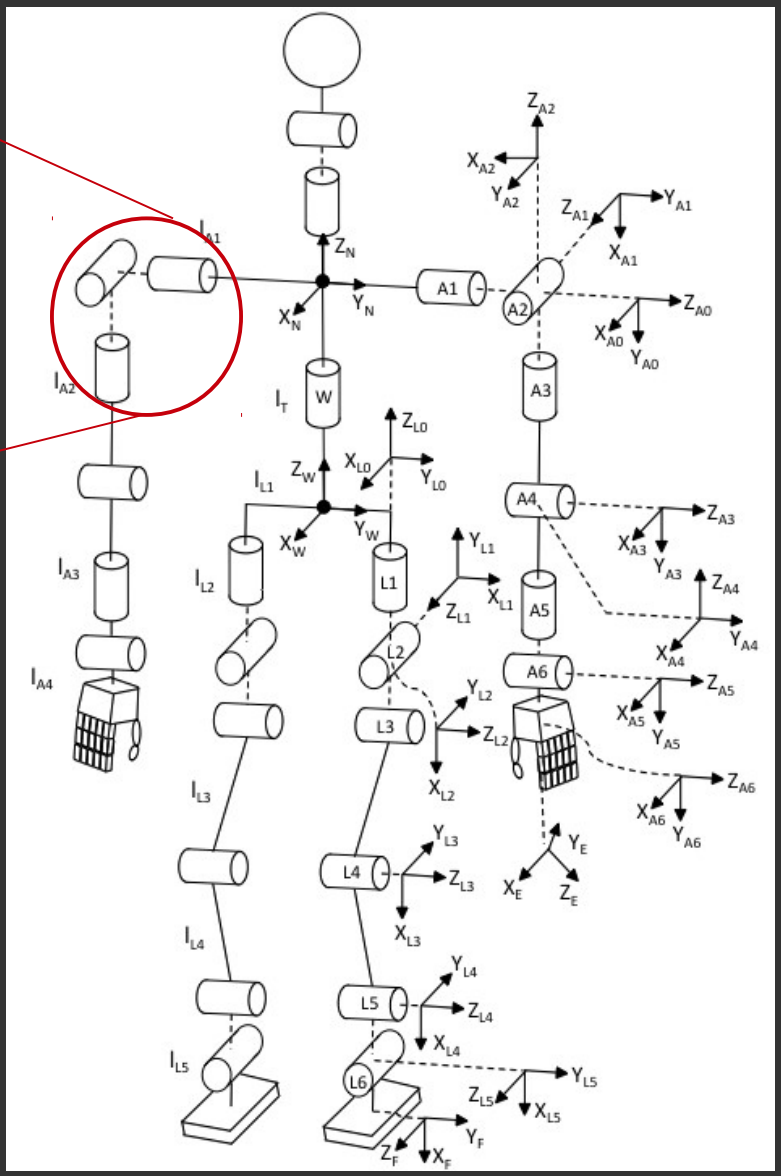
Forward Kinematics:

- Denavit-Hartenberg TFs

Inverse Kinematics:

- Peiper [2] technique
- Ali et. al. [3]





[2] D. L. Peiper, “The Kinematics of Manipulators Under Computer Control,” Oct. 1968.

[3] M. A. Ali, H. A. Park, and C. S. G. Lee, “Closed-form Inverse Kinematic Joint Solution for Humanoid Robots,” pp. 704–709, 2010.

IK Solution Selection

Difficulties

- Arm has 3 different types of singularity conditions
- Arm and Leg IK have 8 solutions each
- Limited workspace due to joint limits

Selection

Goal inside workspace:

- Select solution that minimizes squared joint values

Goal outside workspace

- Select solution with position closest to desired position

[4] Rowland O'Flaherty, Peter Vieira, M.X. Grey, Paul Oh, Aaron Bobick, Magnus Egerstedt, and Mike Stilman. *Kinematics and Inverse Kinematics for the Humanoid Robot HUBO2+*. no. GT-GOLEM-2013-001. Georgia Institute of Technology, Atlanta, GA. 2013.

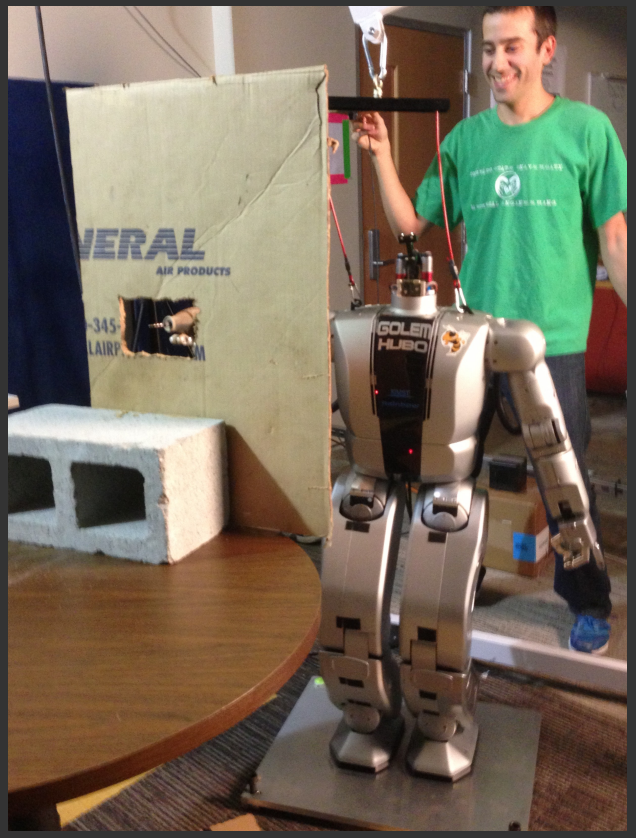
Teleoperation

Polhemus Motion Tracker

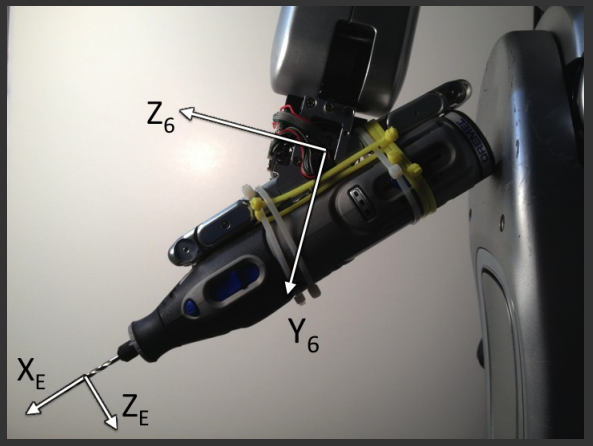
6 DOF
240 Hz
3.5 ms latency

Teleoperation

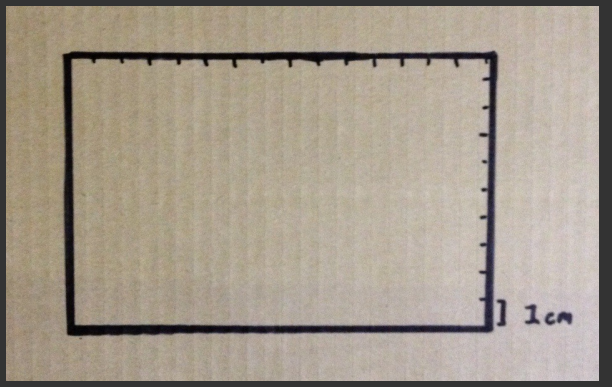
Putting it all together



Setup



Hand & Drill Frames



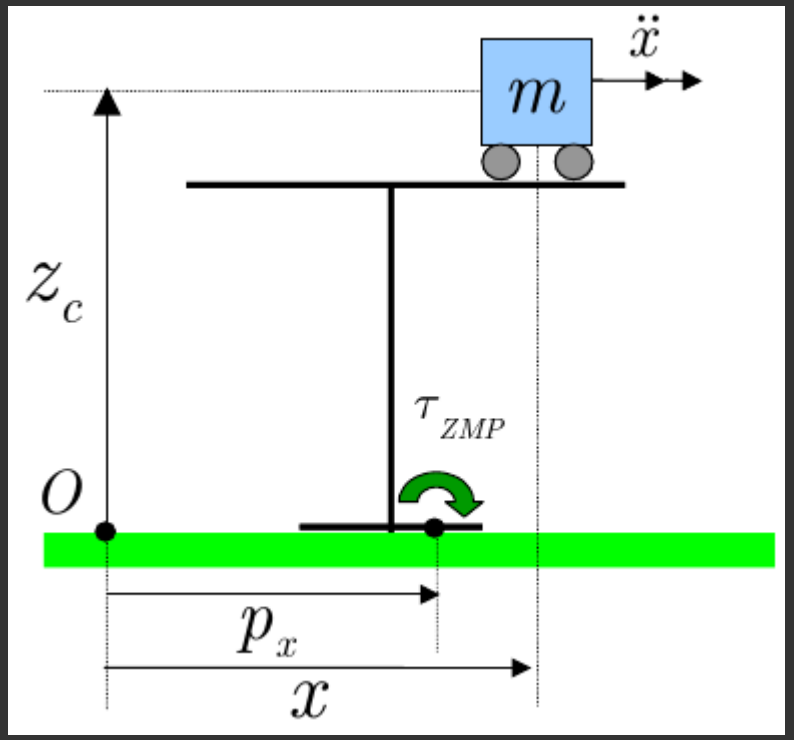
Rectangle to cut out (15 x 10 cm)

[5] Rowland O'Flaherty, Peter Vieira, M.X. Grey, Paul Oh, Aaron Bobick, Magnus Egerstedt, and Mike Stilman. Proc. 5th IEEE International Conference on Technologies for Practical Robot Applications, 2013.

Wall Breaking for TEPRA

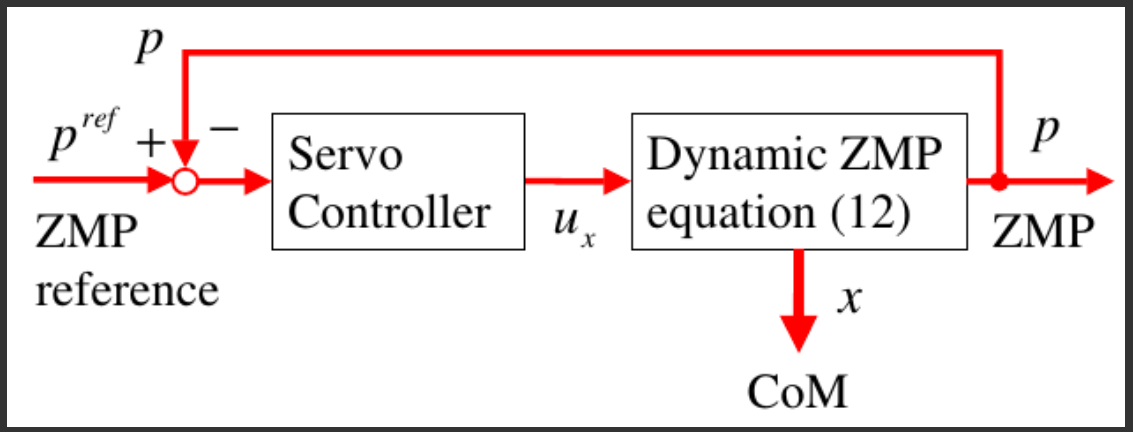
10x

ZMP Walking



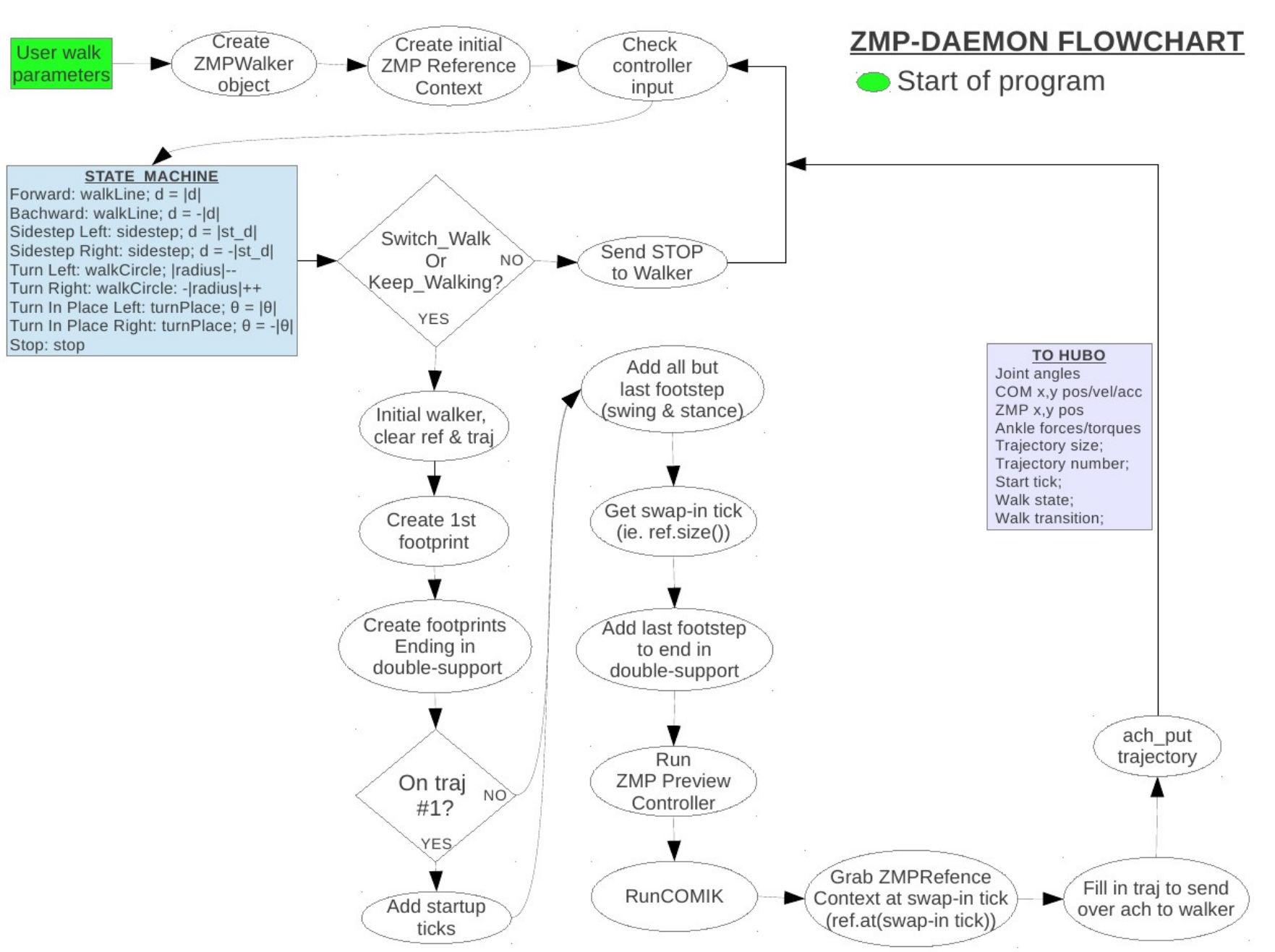
$$p_y = y - \frac{z_c}{g}\ddot{y}$$

$$p_x = x - \frac{z_c}{g}\ddot{x}$$

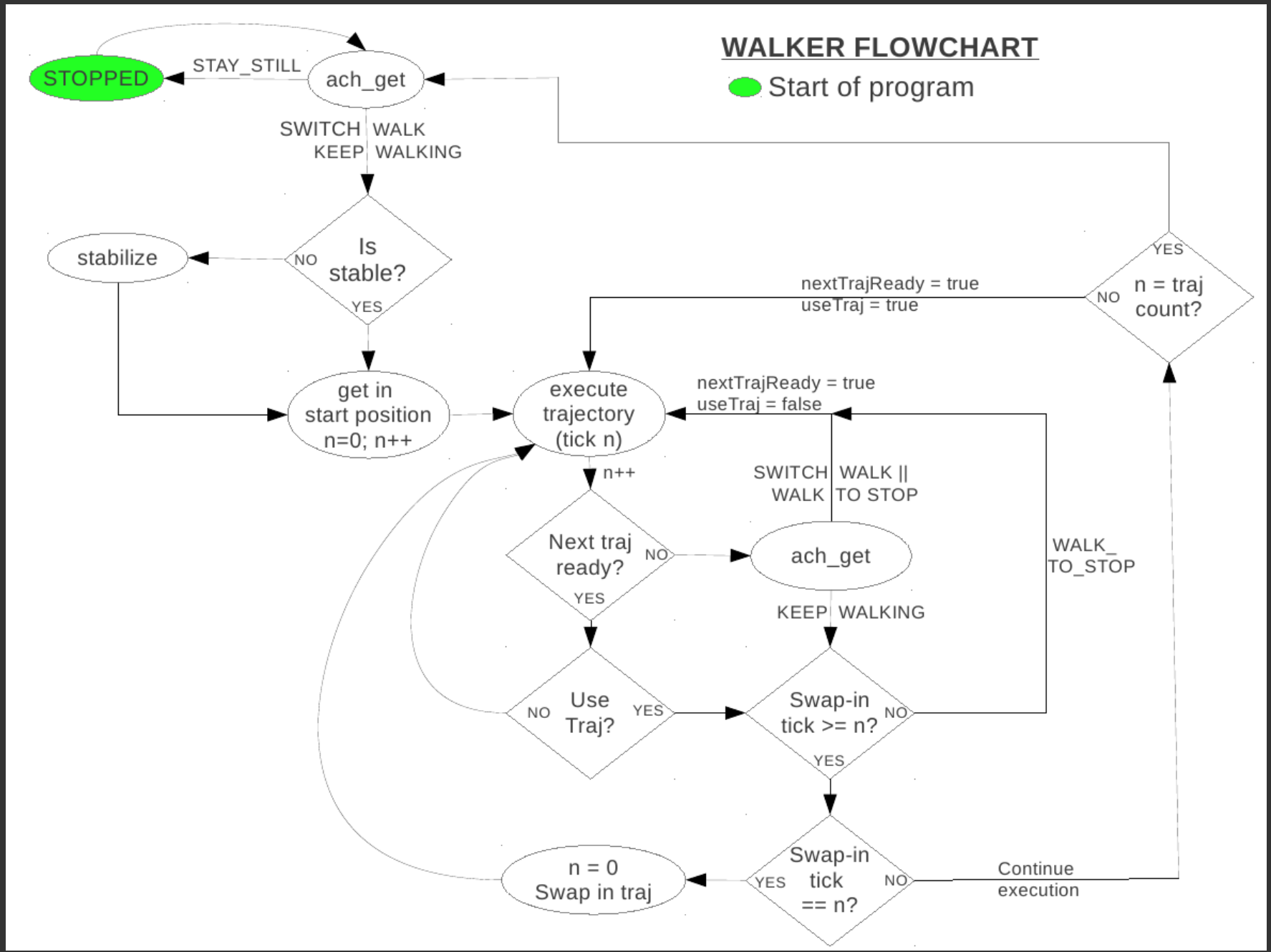


[6] Kajita, Shuuji, et al. "Biped walking pattern generation by using preview control of zero-moment point." Robotics and Automation, 2003. Proceedings. ICRA'03. IEEE International Conference on. Vol. 2. IEEE, 2003.

ZMP Daemon


ZMP-DAEMON FLOWCHART
Start of program
User walk parameters
Create ZMPWalker object
Create initial ZMP Reference Context
Check controller input
STATE_MACHINE
Forward: walkLine; d = |d|
Bachward: walkLine; d = -|d|
Sidestep Left: sidestep; d = |st_d|
Sidestep Right: sidestep; d = -|st_d|
Turn Left: walkCircle; |radius|--
Turn Right: walkCircle: -|radius|++
Turn In Place Left: turnPlace; θ = |θ|
Turn In Place Right: turnPlace; θ = -|θ|
Stop: stop
Switch_Walk Or Keep_Walking?
NO
YES
Send STOP to Walker
Initial walker, clear ref & traj
Create 1st footprint
Create footprints Ending in double-support
On traj #1?
NO
YES
Add startup ticks
Add all but last footstep (swing & stance)
Get swap-in tick (ie. ref.size())
Add last footstep to end in double-support
Run ZMP Preview Controller
RunCOMIK
Grab ZMPRefence Context at swap-in tick (ref.at(swap-in tick))
Fill in traj to send over ach to walker
ach_put trajectory
TO HUBO
Joint angles
COM x,y pos/vel/acc
ZMP x,y pos
Ankle forces/torques
Trajectory size;
Trajectory number;
Start tick;
Walk state;
Walk transition;

Real-time Continuous Walking



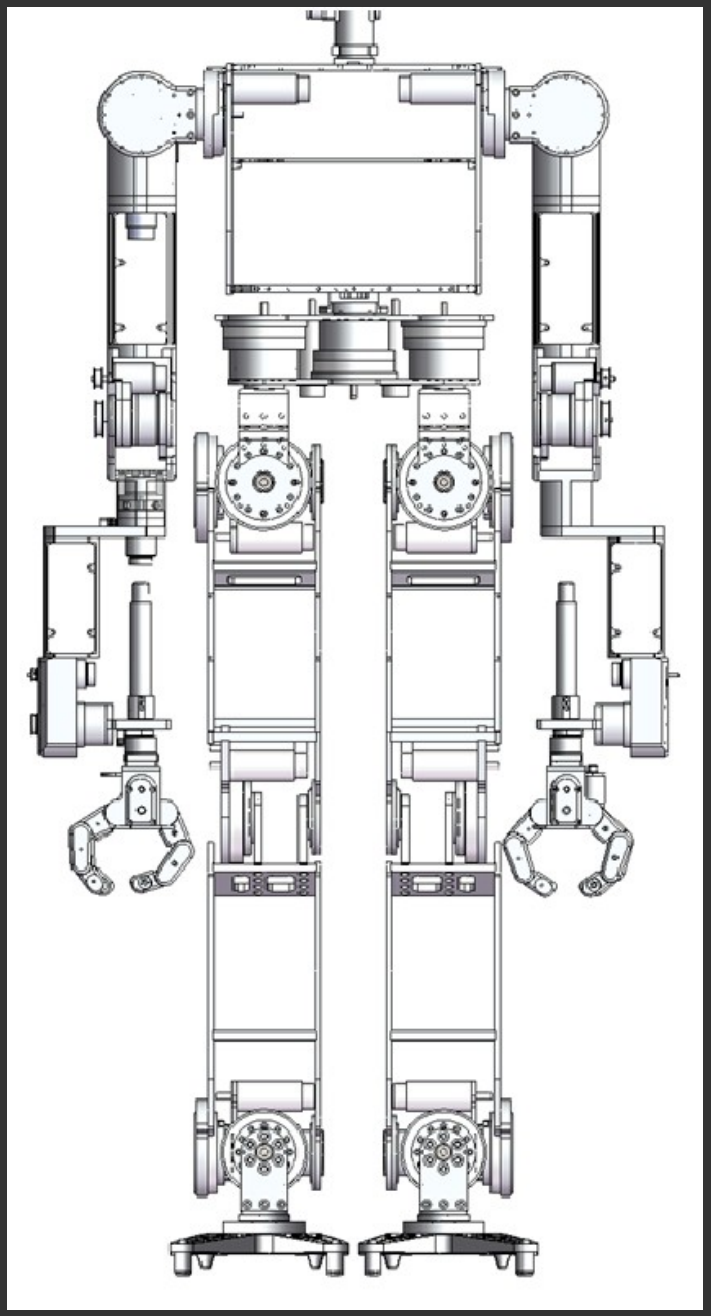
Walking - Simulation

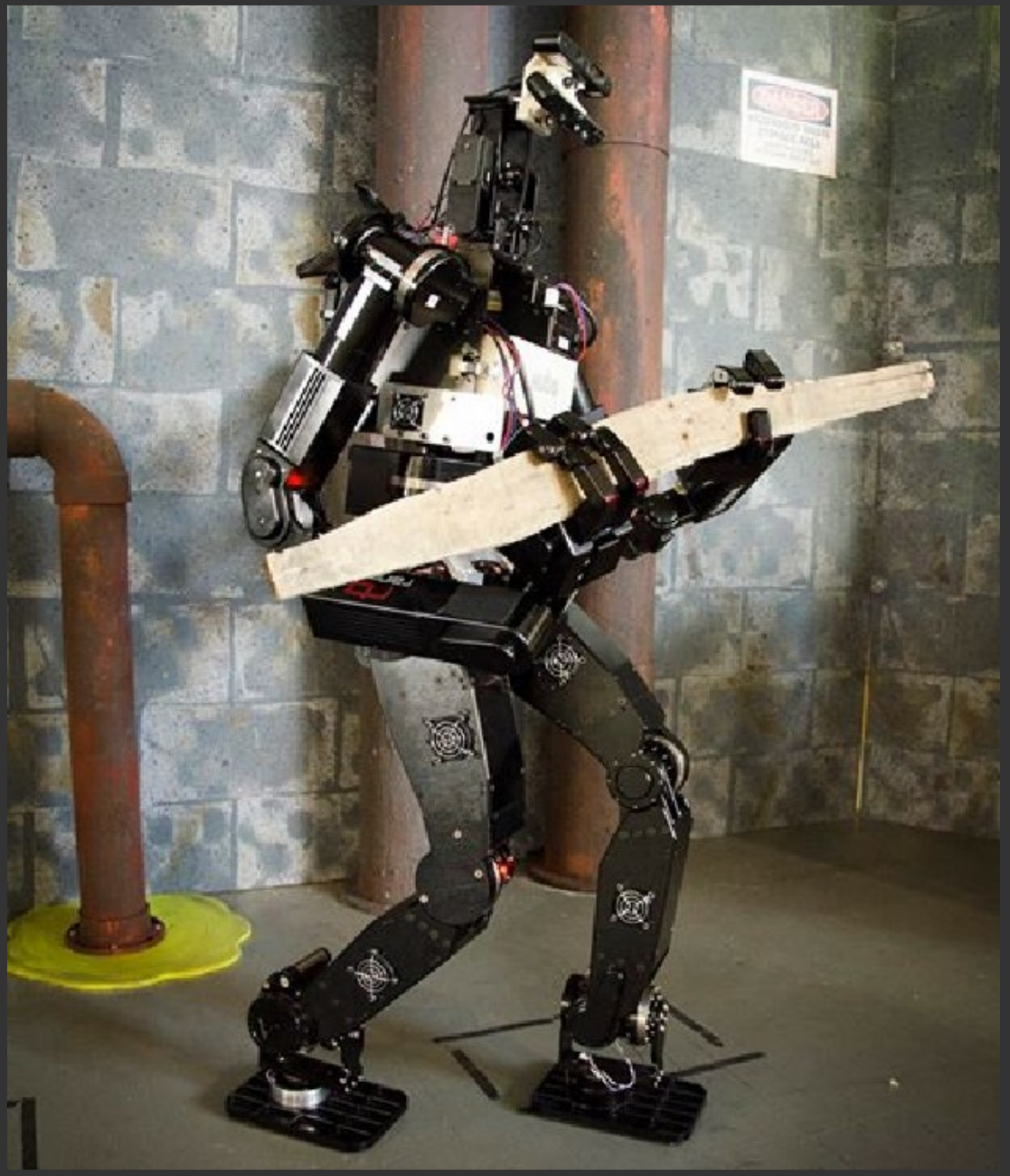
Walking – The real thing

Critical Design Review

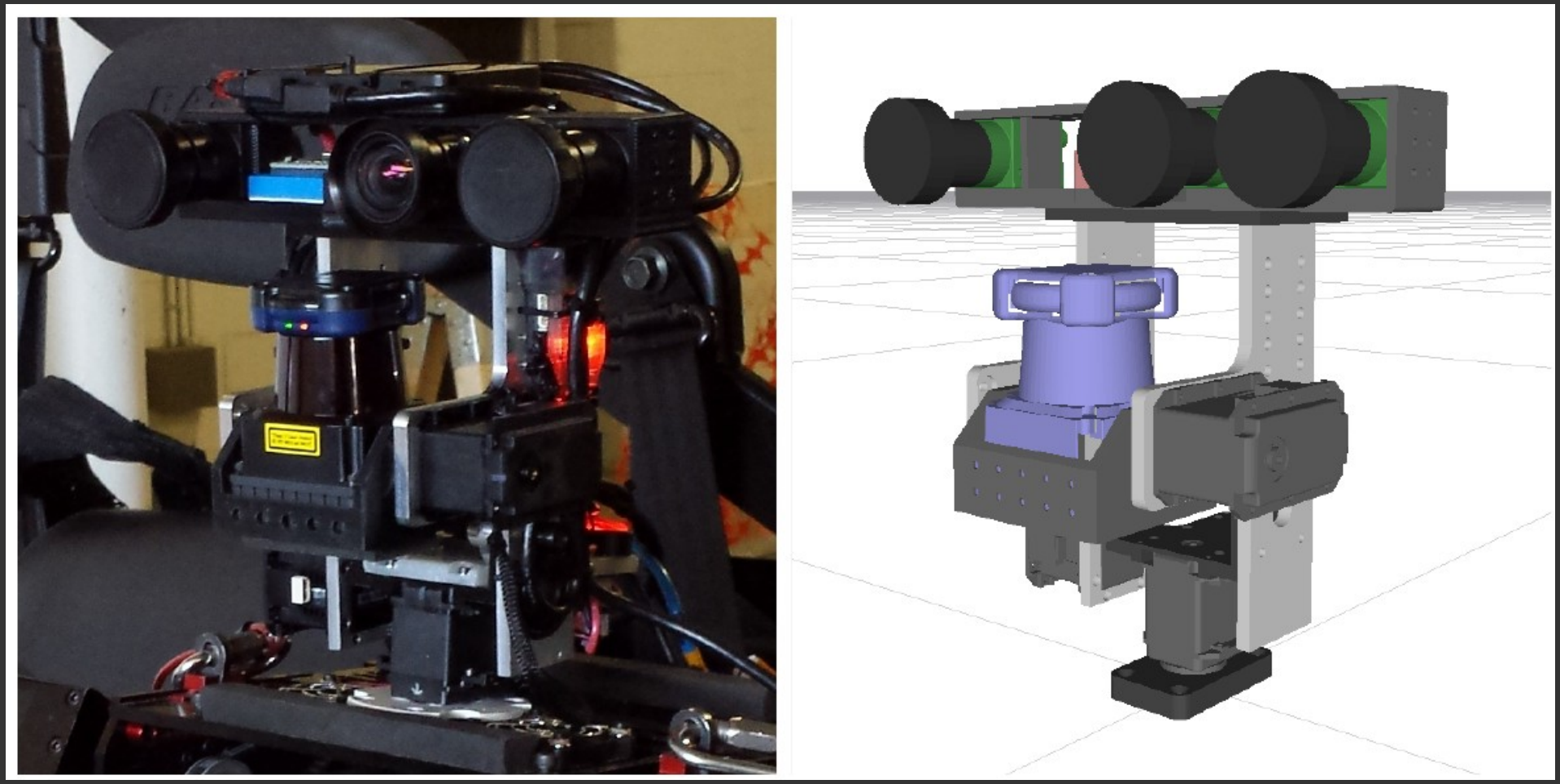
4x speed

DRC-HUBO





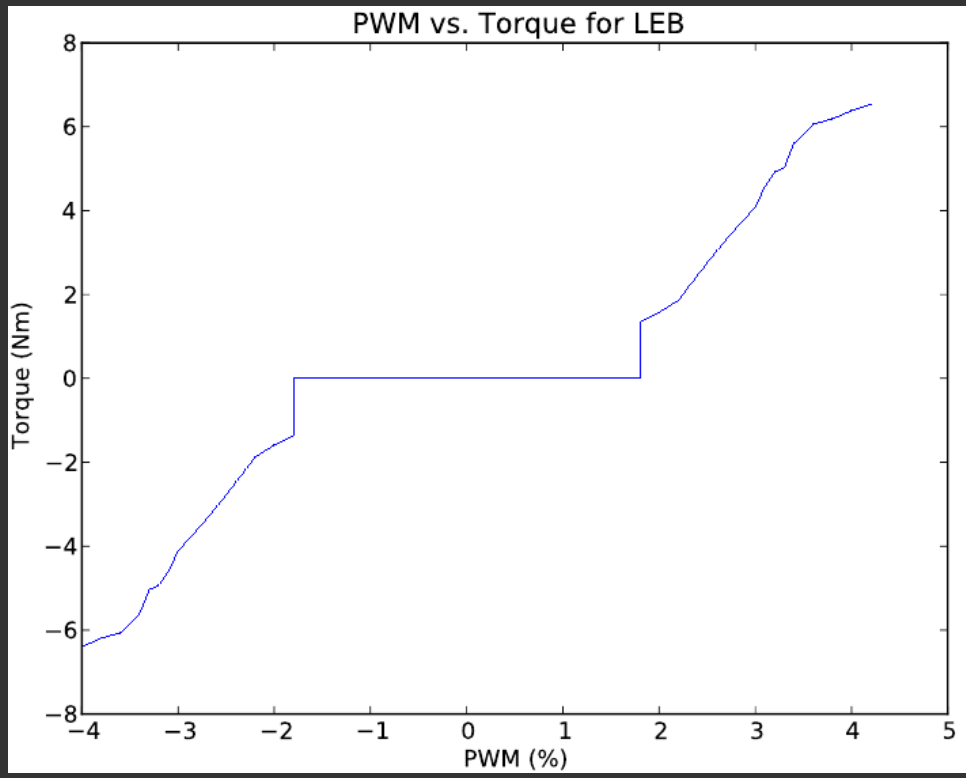
Perception Suite

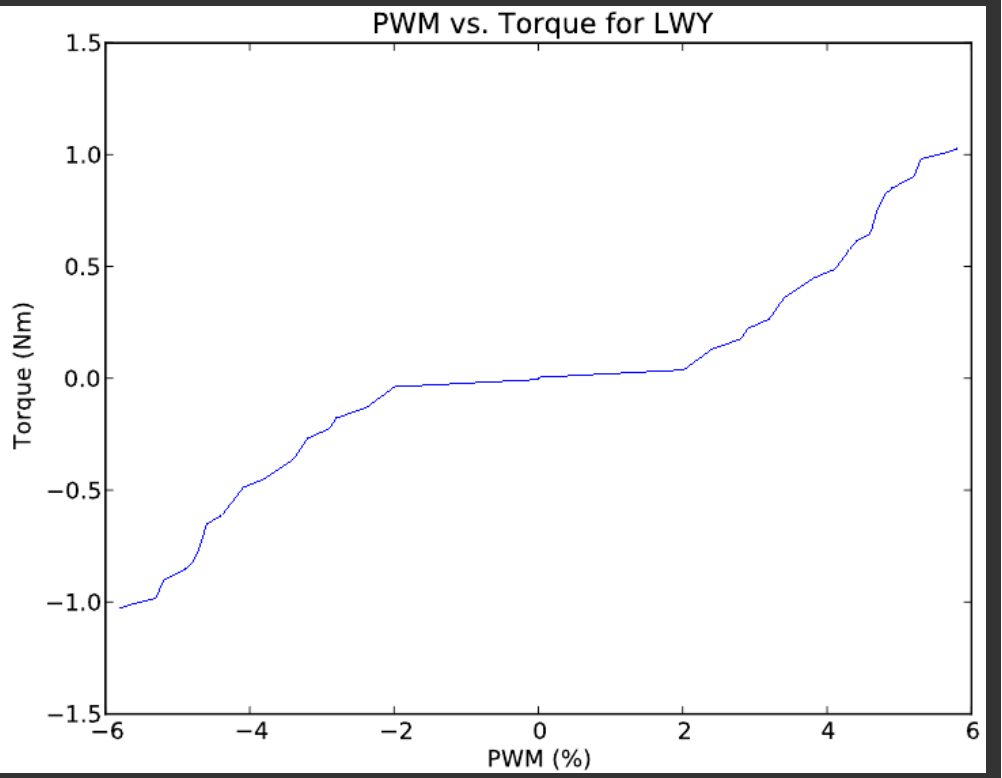


3 x Pt. Grey Flea3 cameras
Hokuyo UTM-30LX-EW laser range-finder

Joint Compliance

Non-complimentary switching mode - PWM





Gravity compensation

Walking Controllers

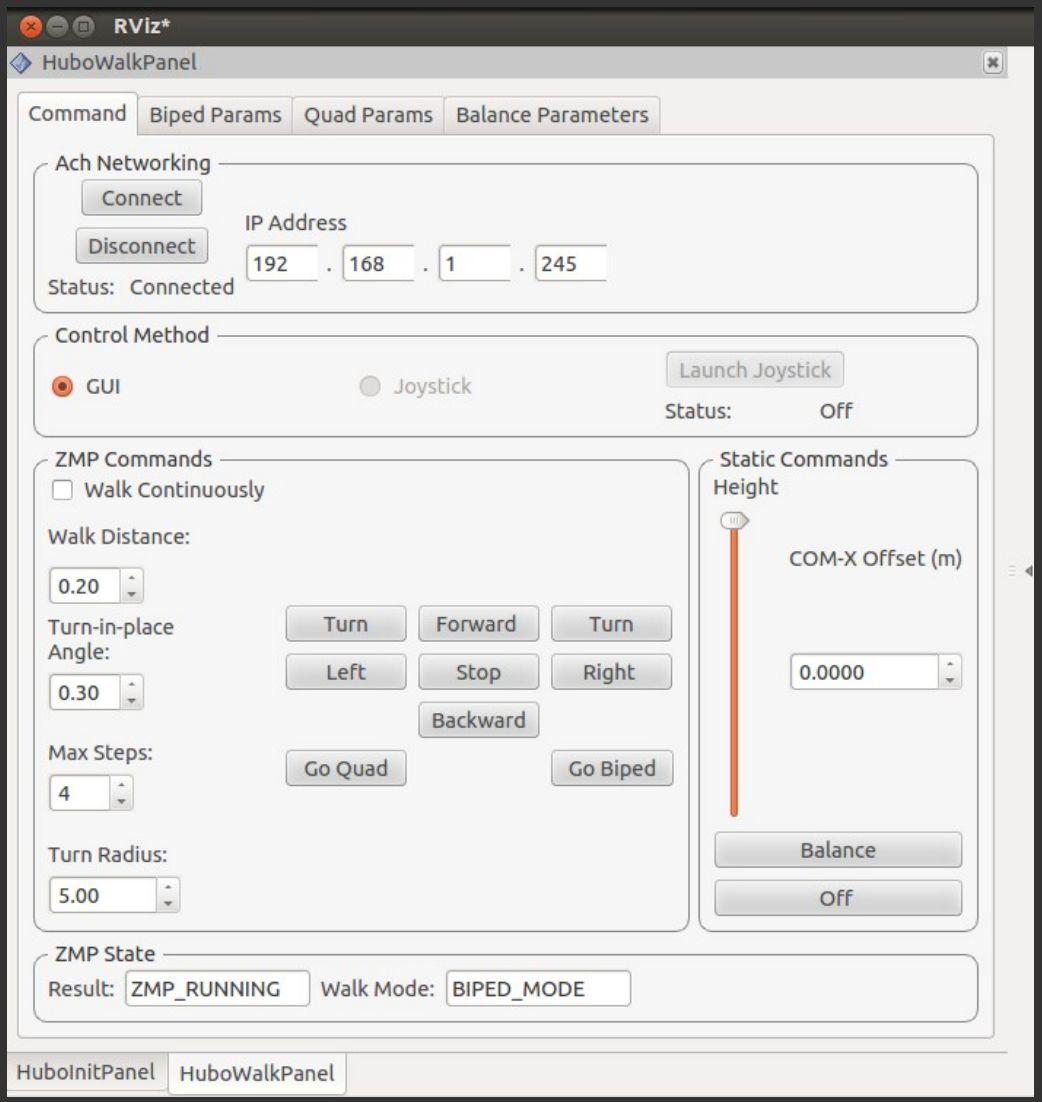
Workspace Balance Controller: Hips

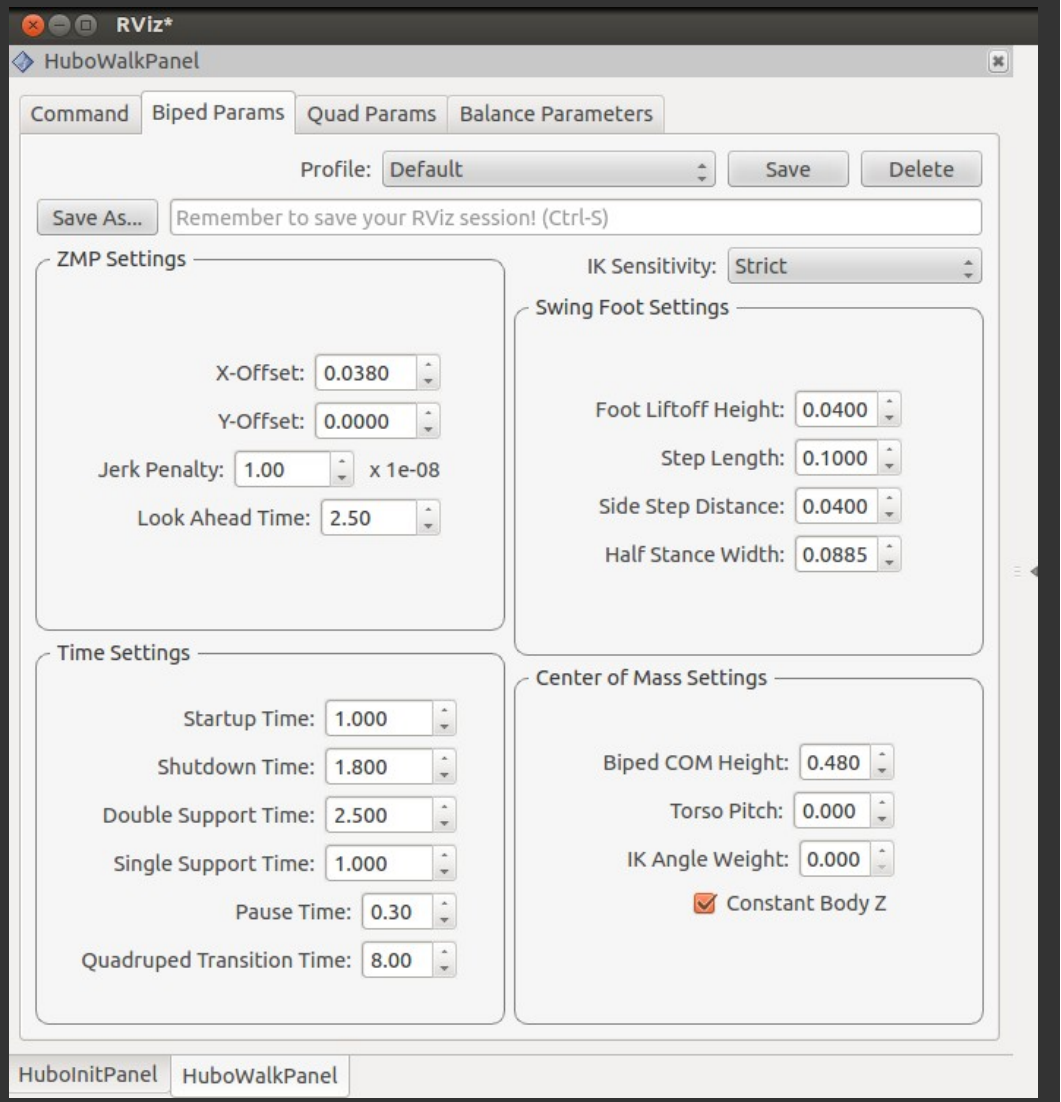
$$M\ddot{\theta}+Q\dot{\theta}+K\theta=\Delta\tau_x=\tau_{x_m}-\tau_{x_d}$$

Workspace Landing Controller

$$M\ddot{z}+Q\dot{z}+Kz=\Delta F_z=F_{z_m}-F_{z_d}$$

Biped/Quadruped Walking





Biped/Quadruped Transition

5x

Some Other Features

Numerical inverse kinematics

Interpolation

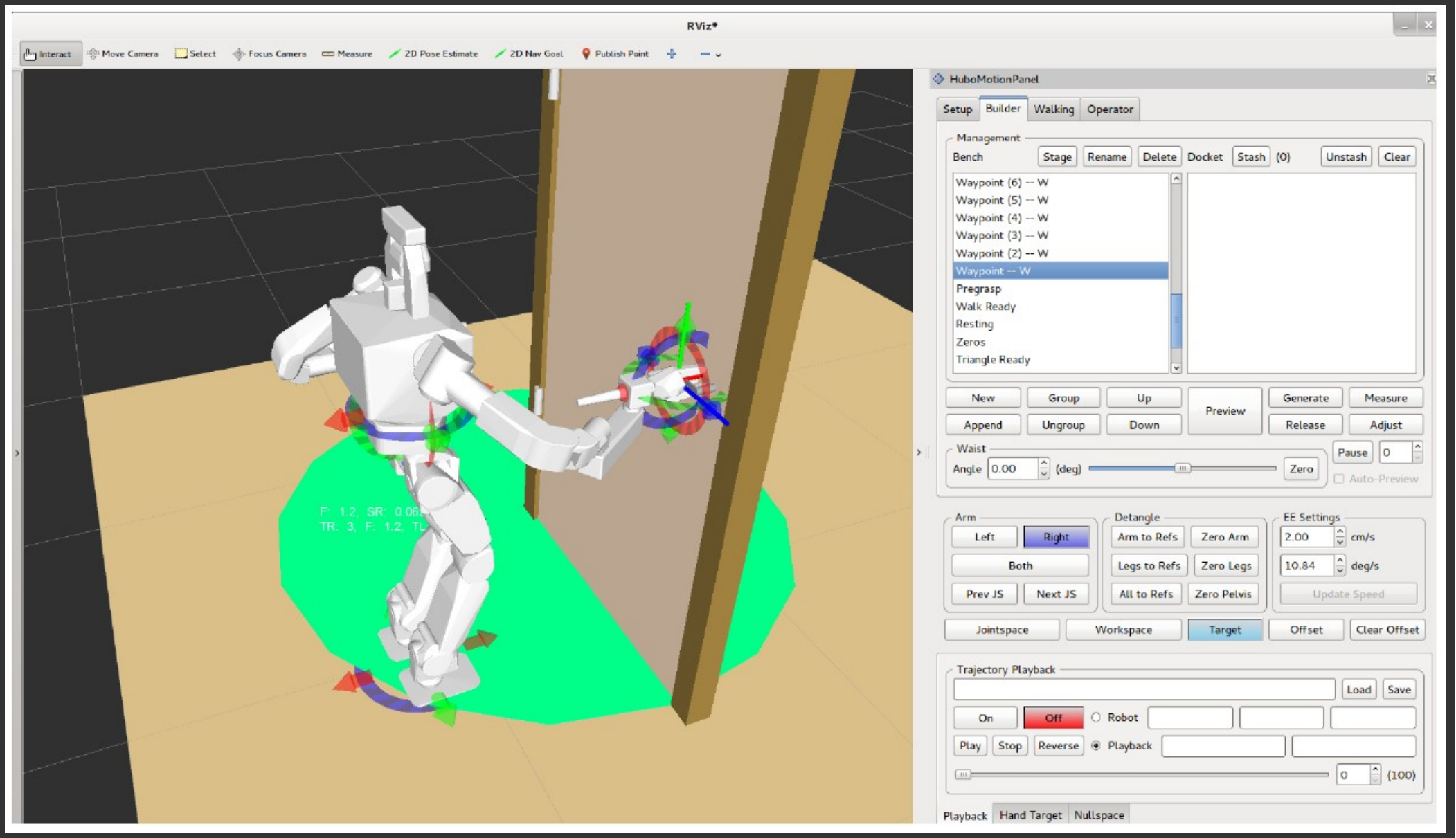
Collision Detection

Perception

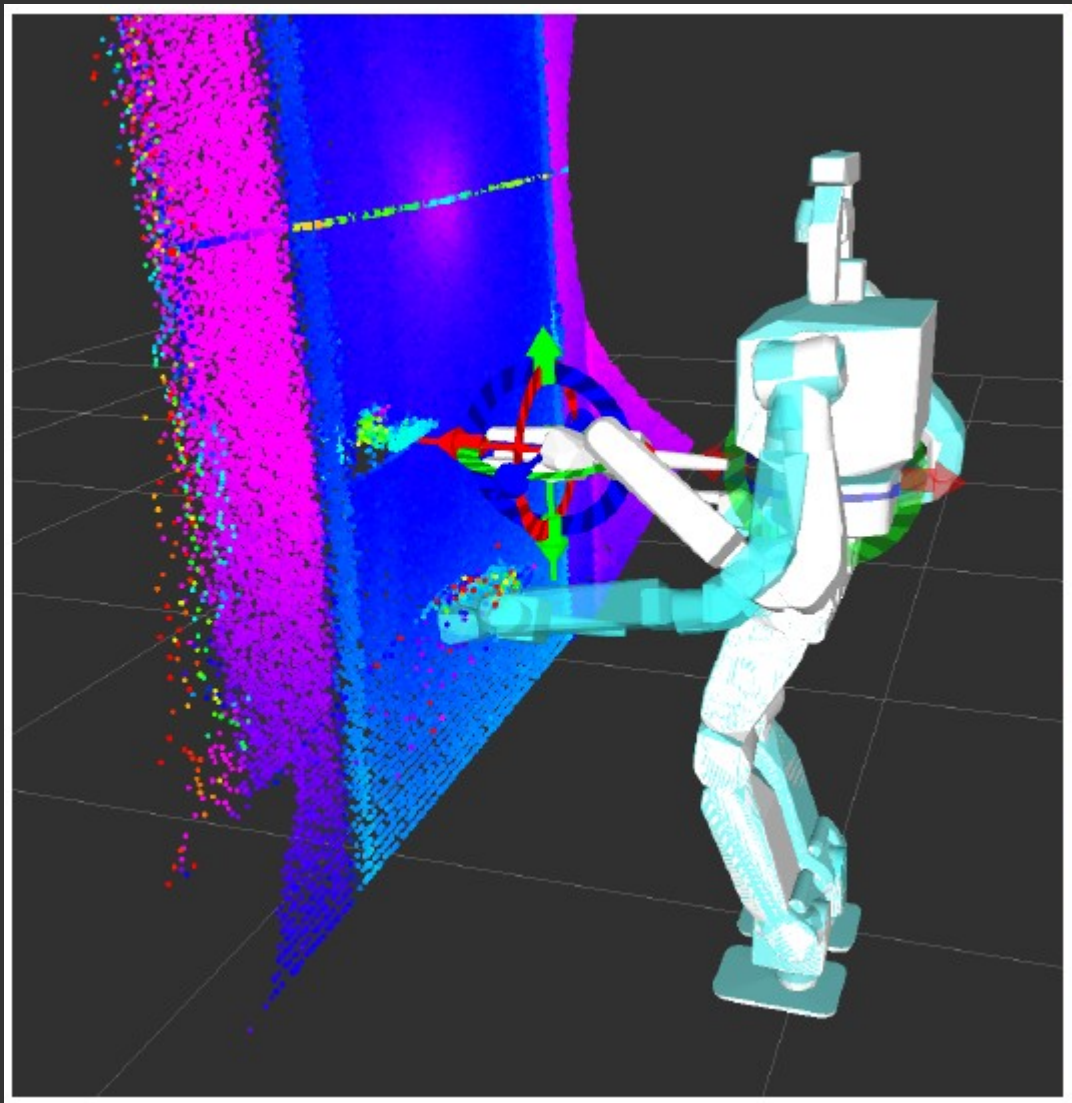
Trajectory Management

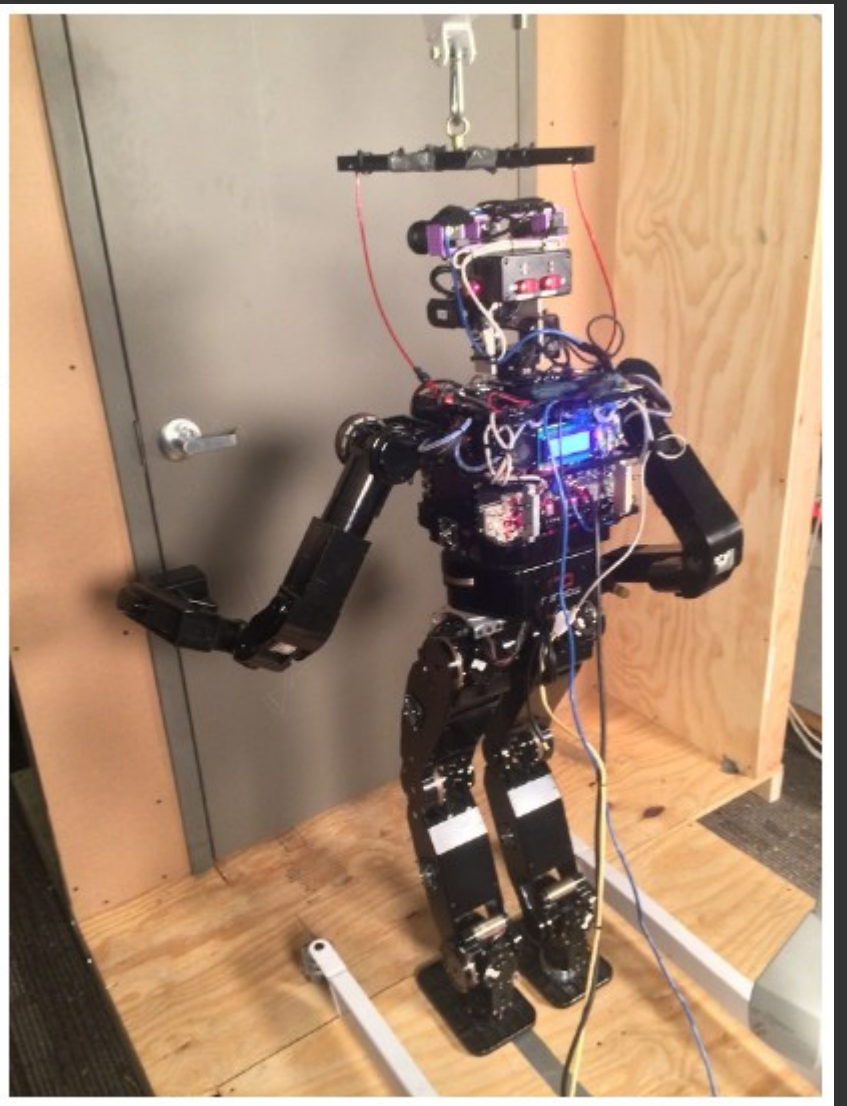
Teleoperation in RViz

Trajectory Designer



Execution Manager

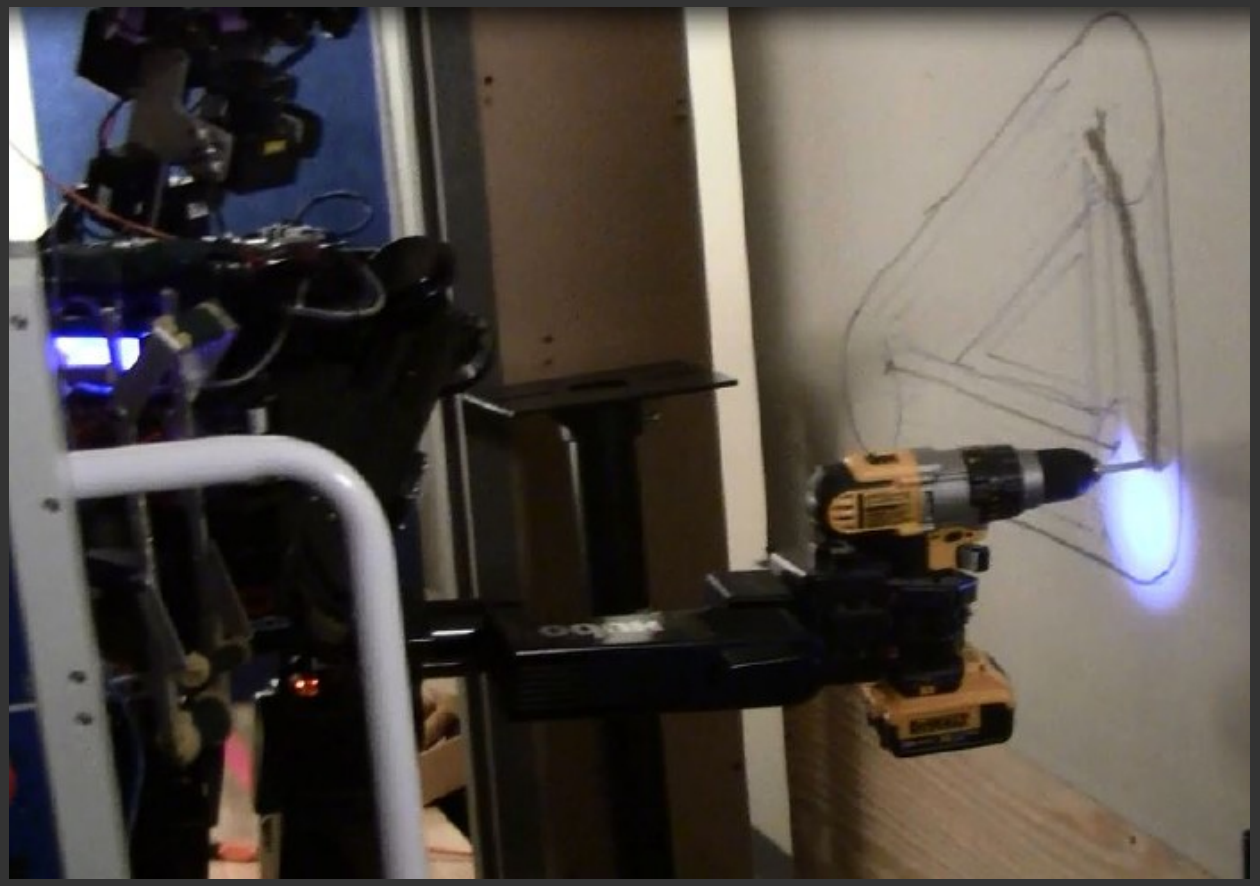


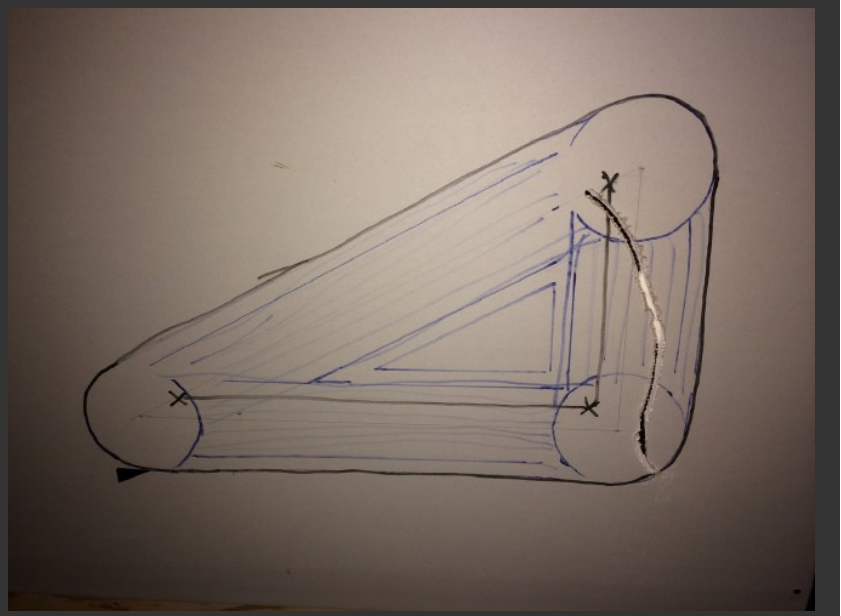


Debris Removal

Practice - 1/3 points, DRC – 0/3 points

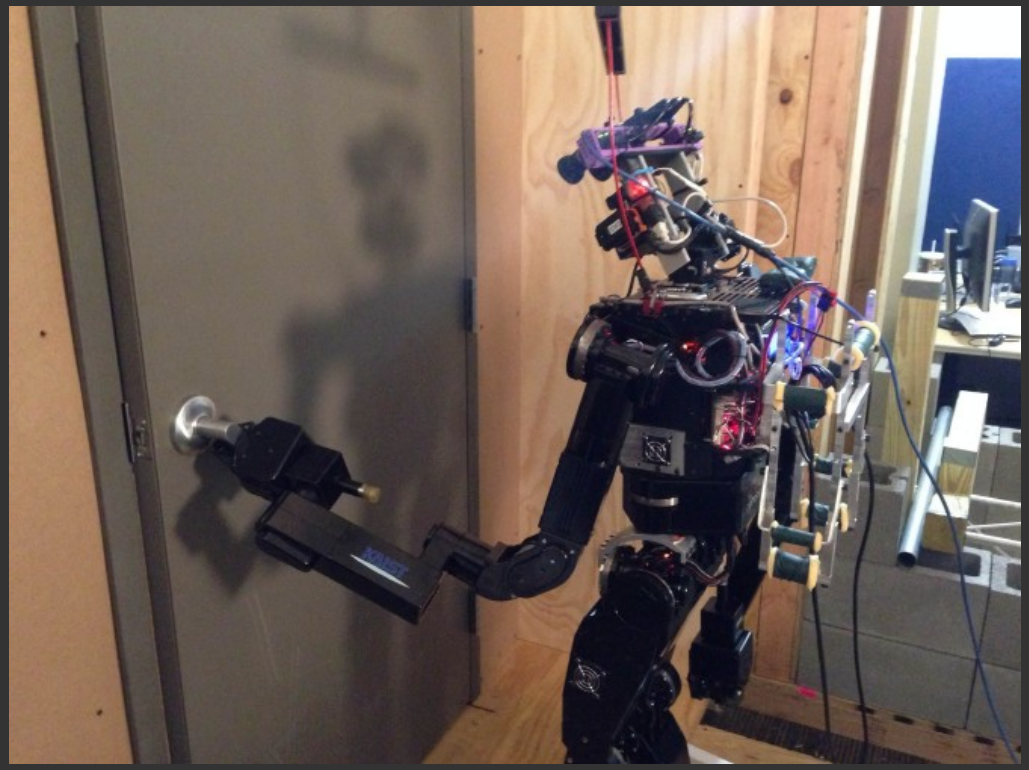
Wall Breaking

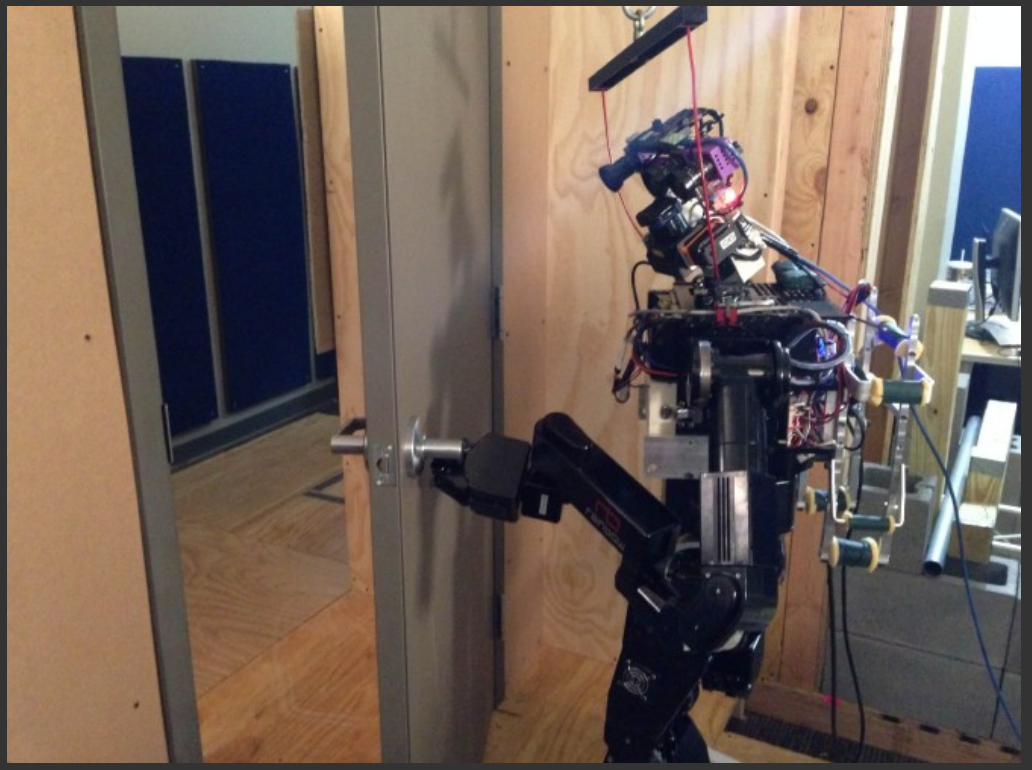




Practice - 2/3 points
DRC – 0/3 points

Door Opening





Practice - 2/3 points
DRC – 0/3 points

Lessons Learned

Event-based task allocation

Managing complexity

- sporadic walking failures -> low-level-software

Walking and dynamic stability

- Several algorithms, but no responsibility

ROS

- TF tree

Communications

- packet buffering, out-of-order packets

Hardware issues

- burnt motors and boards. Need safety systems

Successes

DRC Practice
- 5/9 points

General-purpose, usable operator software
- Same SW for all three events

Simple implementations
- Limit complete planners and feedback controllers.

Agile development
- Whiteboard of prioritized tasks

ROS
- Point clouds, Dynamixels, GUI

Ach
- Stable, low latency, configurable