State of Talos
@ University of Waterloo

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ROBOHUB

Contents

University of Waterloo / RoboHub

- RoboHub is a robotics research facility backed by an infrastructure grant from the Canada Foundation for Innovation (CFI)
- Started with five associated labs covering every aspect of robotics
- Range of robotic systems
- Access to robots is possible (for people from Canada)

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uwaterloo.ca/robohub

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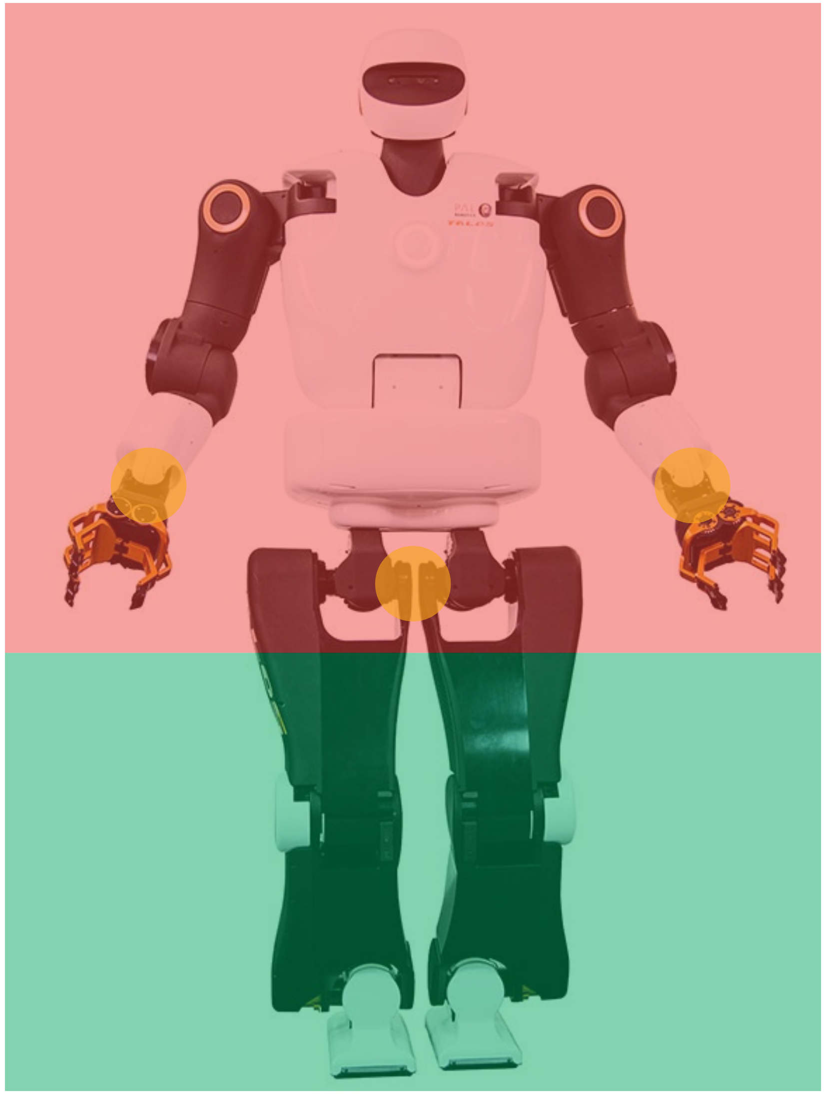
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

ONTARIO Advanced Manufacturing Consortium

Platform Review

Mechanical Structure



- Exoskeleton/Skeleton construction
- Contact only at designated spots
- Plastic covers can break
- Paint scratches
- Frequent self collisions between legs
- Pinch points at the wrists

Position Control

- Stiffness of joint level control is good
- Structure stiffness low at some points
- Oscillations between position control and structure possible
- Lack of stiffness could effect locomotion performance

Torque Control

- ✔ Zero torque/gravity compensation
- ✗ Currently not enough torque control bandwidth for
  - ✗ Clean rendering of potential field end stops
  - ✗ Dynamic stepping?
- ✗ Torso torque control friction is high

- Not the latest version
- Performance could be limited by sensor data acquisition

Manipulating the arm position with small forces

Reliability

✔ Overall reliability is good

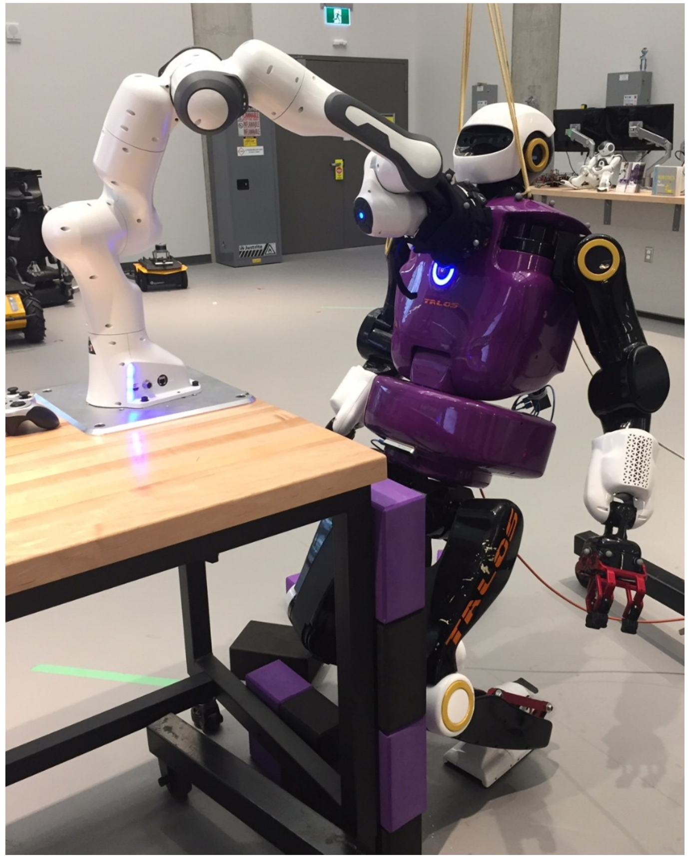
✗ WiFi

✗ 1x Torque sensor

✗ Hip-Z encoders

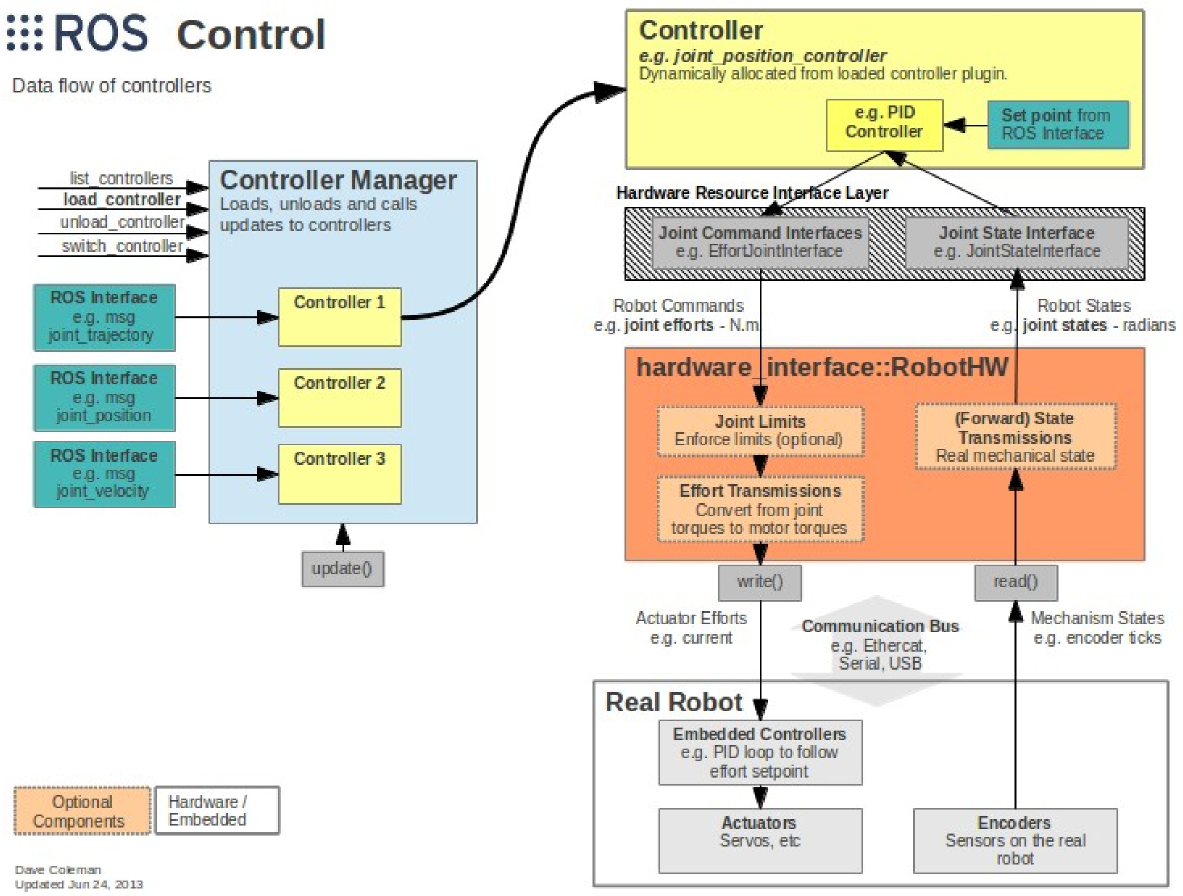
Crash Survivability

- 1 bad line of code, huge torques commanded
- 4x HDs locked up
- 1x Torque Sensor beyond repair
- 3 days diagnosis, 3 days repair with 2 PAL employees



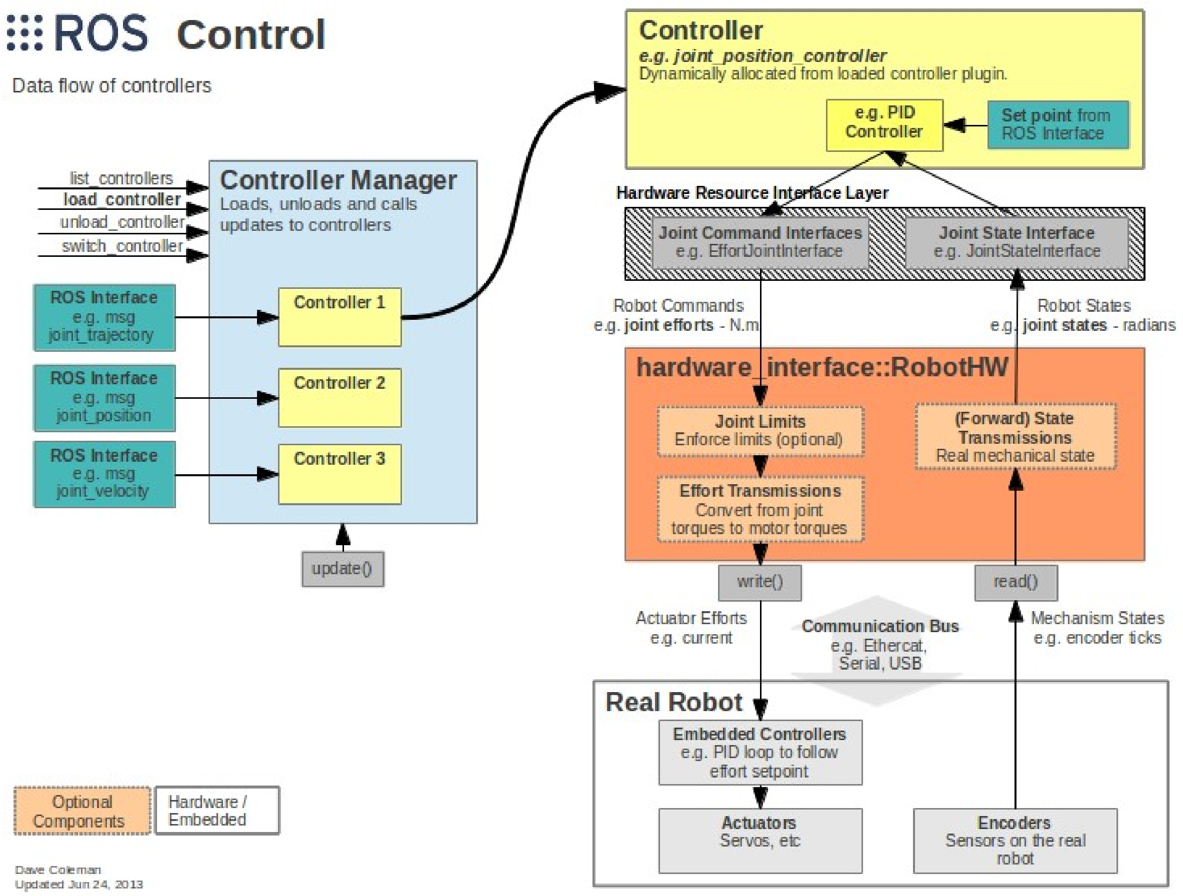
Software stack: ros_control

- ✔ Good plugin infrastructure for compositing controllers
- ✗ Slow development: reloading controller requires restart of hardware abstraction layer
- ✗ τ_d interface not available



Software stack: pal_base_controller

- Wraps a custom controller
- Provides torque control layer, τ_d
- Protects robot against destructive controller commands
- 0.3ms available computation time for a torque control whole body controller
- Real-time not strictly enforced
- τ measurements not available



Summary

- Reliable and robust robot

Most relevant issues:

- Torque control bandwidth
- Structure elasticity of hip joints

Whole Body Control

Existing whole body control frameworks for Talos

- pal_wbc
- Stack of Tasks (SOT)

Goals for “usable WBC”

- Safe, reliable and robust controller
- Good interfaces for step recovery/locomotion
- Compliant, human-friendly behavior
- Balancing with uncertain contacts

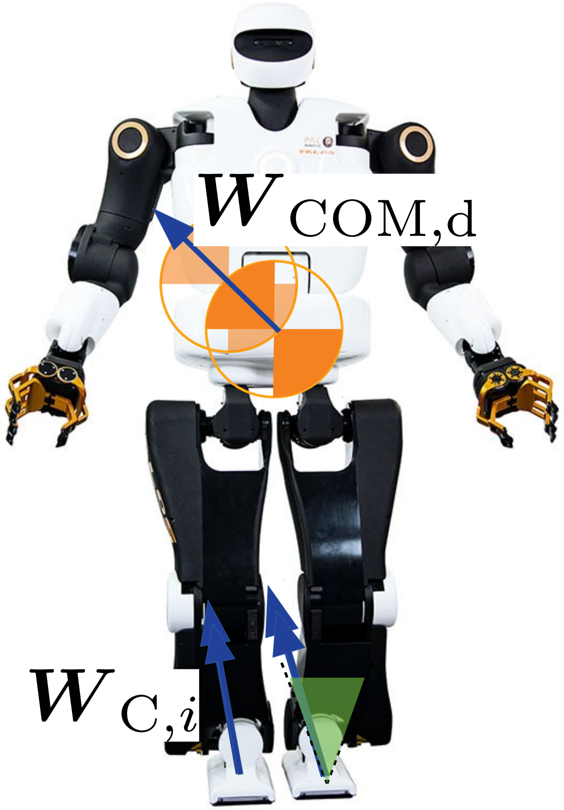
Passivity-based Whole Body Control

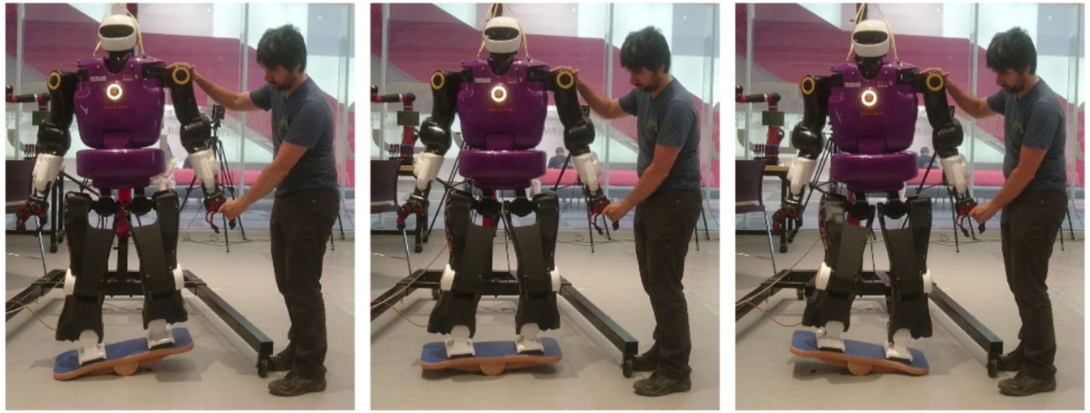
Based on Henze et al. Passivity-based whole-body balancing for torque-controlled humanoid robots in multi-contact scenarios 2016 (IJRR)

$$\boldsymbol{M}\ddot{\boldsymbol{q}} + \boldsymbol{C}\dot{\boldsymbol{q}} + \boldsymbol{g} = \begin{bmatrix} \boldsymbol{0} \\ \boldsymbol{\tau} \end{bmatrix} + \sum \boldsymbol{J}_{\mathrm{C},i}^{\mathrm{T}} \boldsymbol{W}_{\mathrm{C},i}$$

$$\min \quad \Gamma = \boldsymbol{W}_{\mathrm{COM,d}} - \sum \mathrm{Adj}_{\mathrm{C},i}^{\mathrm{T}} \boldsymbol{W}_{\mathrm{C},i}$$

s.t. contact wrench constraints

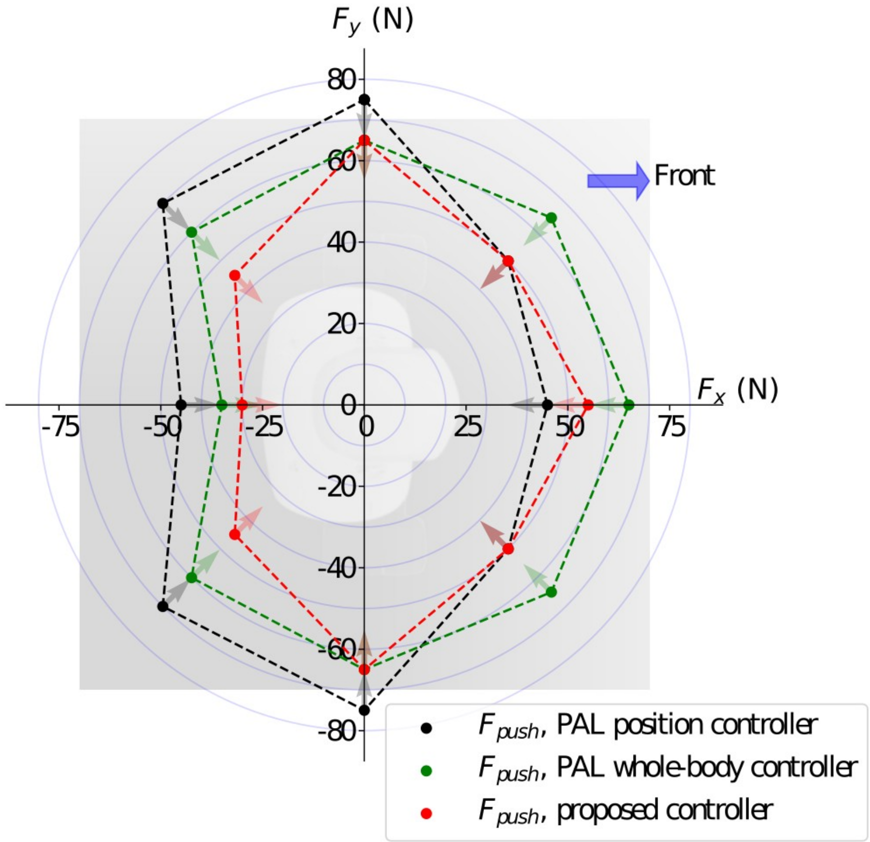




Passivity-based Whole Body Control: Results

First quantitative tests:

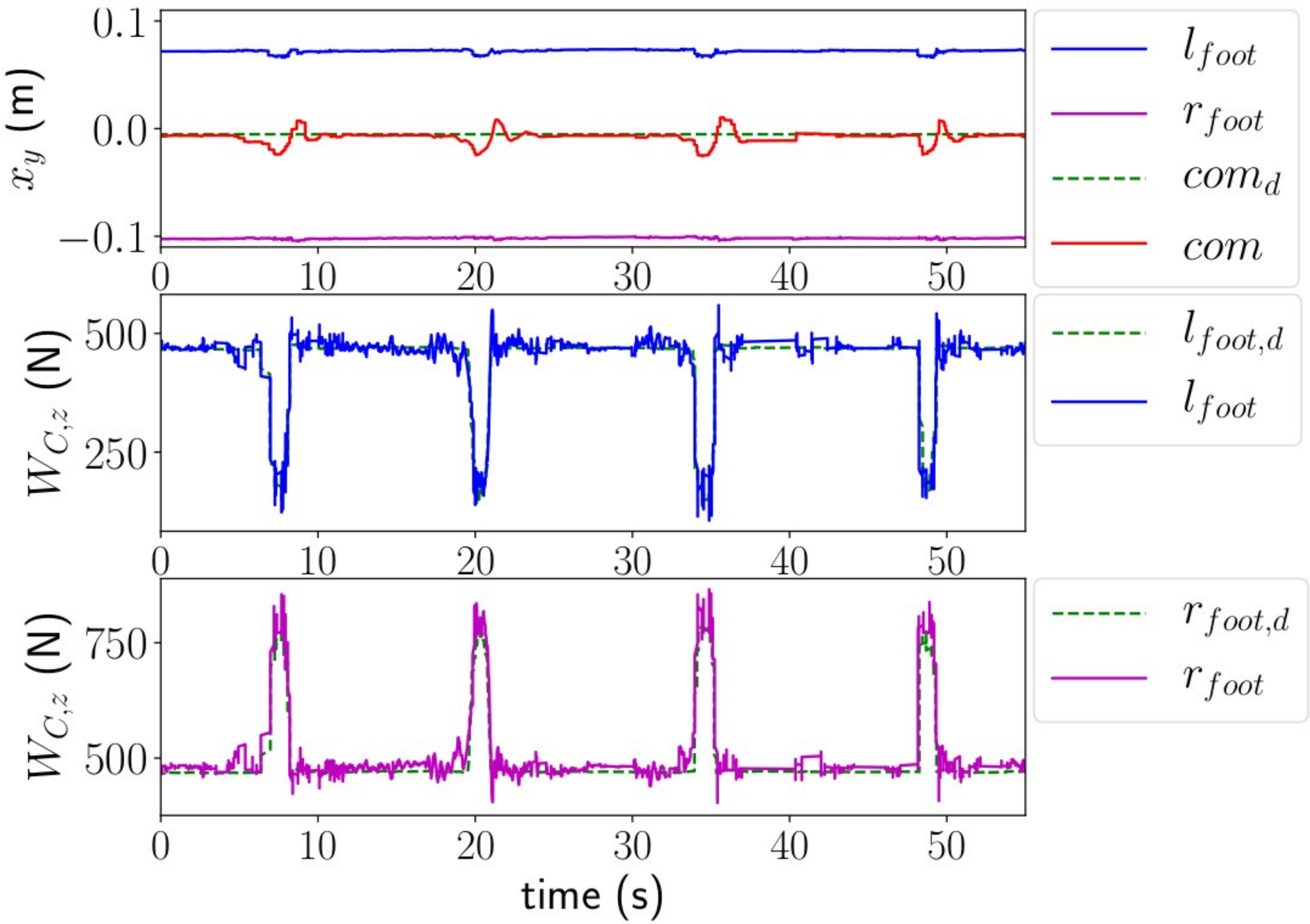
- Resisting a static force



Passivity-based Whole Body Control: Force Control

First quantitative tests:

- Resisting a static force



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State Estimation: Motivation

With uncertain contacts / highly dynamic motions a state estimation using IMU and kinematics is not reliable.

Solutions:

- External sensing (cheating)
- Visual odometry (with depth perception)

Boston Dynamics: Spot Mini

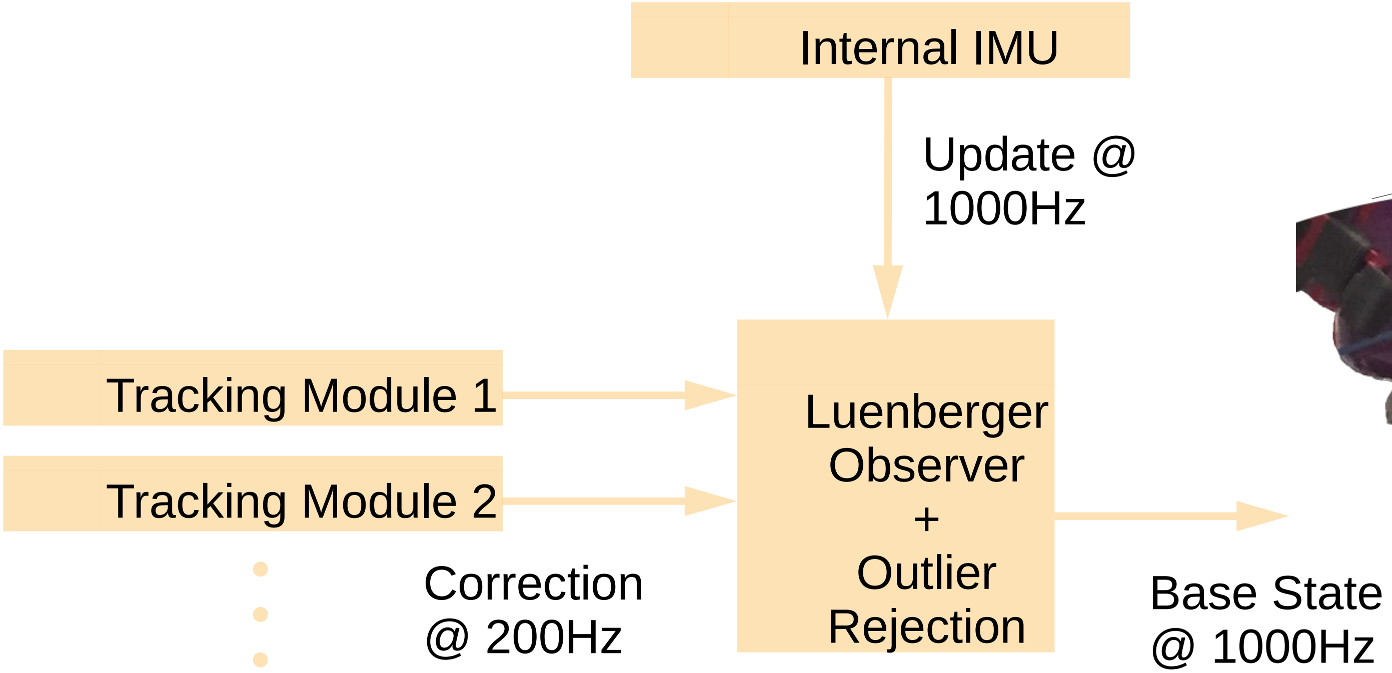
Intel RealSense Tracking Camera T265

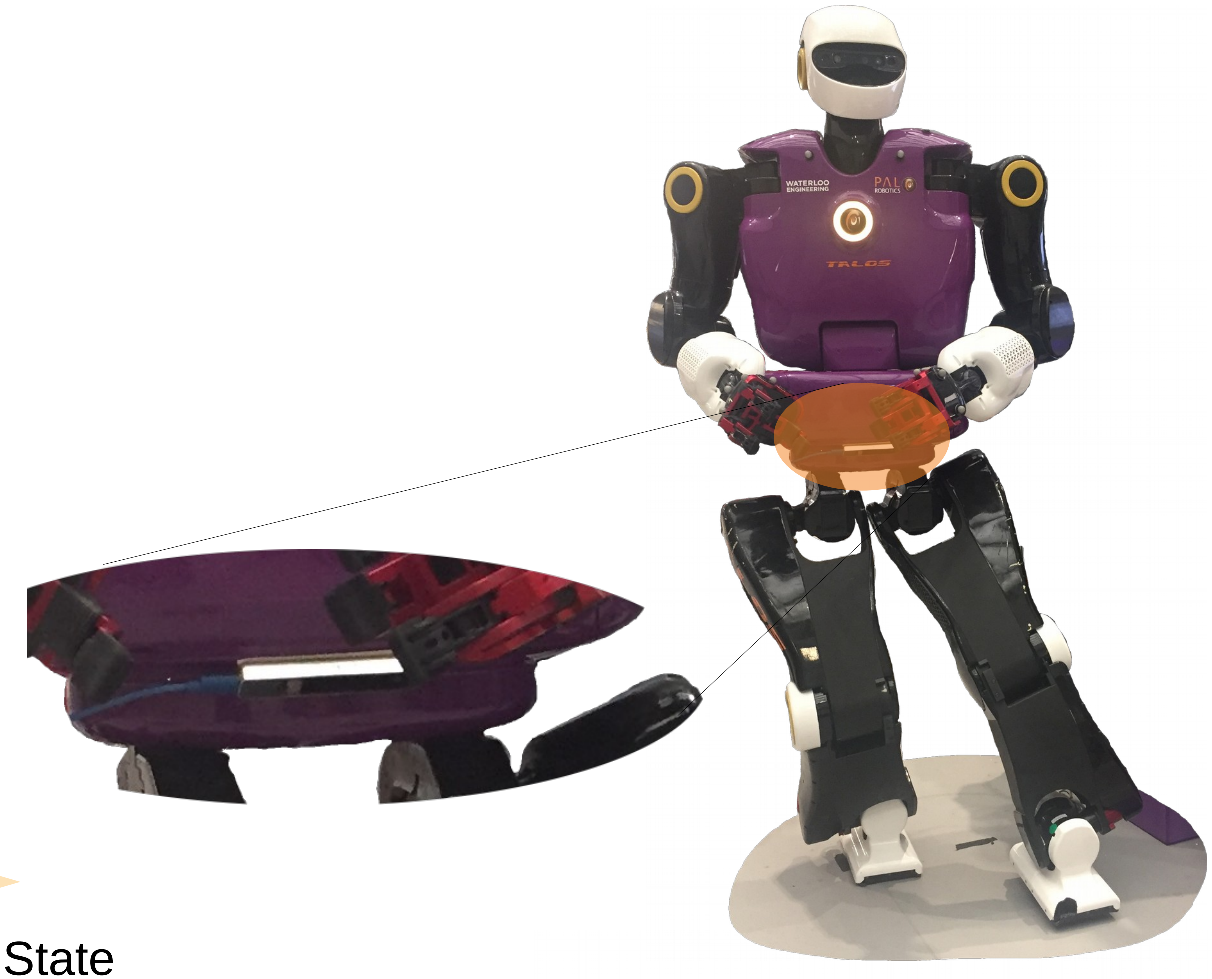
- Integrated Visual Odometry based on passive stereo cameras
- Wide-angle optics
- IMU
- Sensor fusion
- Output: 200Hz, 6ms latency (advertised)
- No covariance output (currently)

Intel: RealSense Tracking Camera

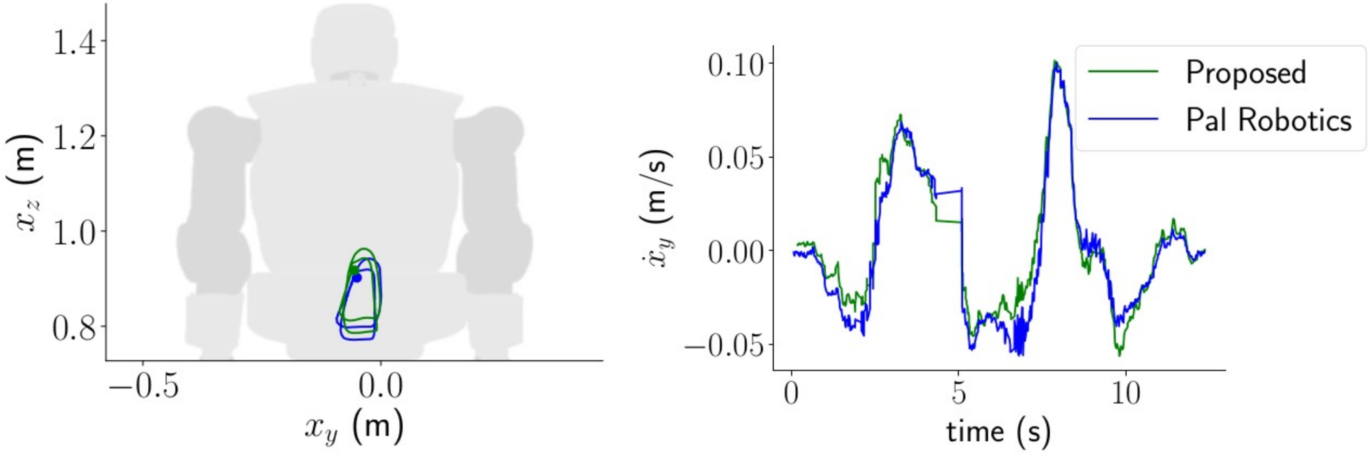
State Estimation: Implementation

- Integration of 2x T265 tracking cameras on Talos
- Use filter to combine internal IMU with data form tracking cameras
- Use this state estimation in balancing control
- Use outlier detection to increase robustness

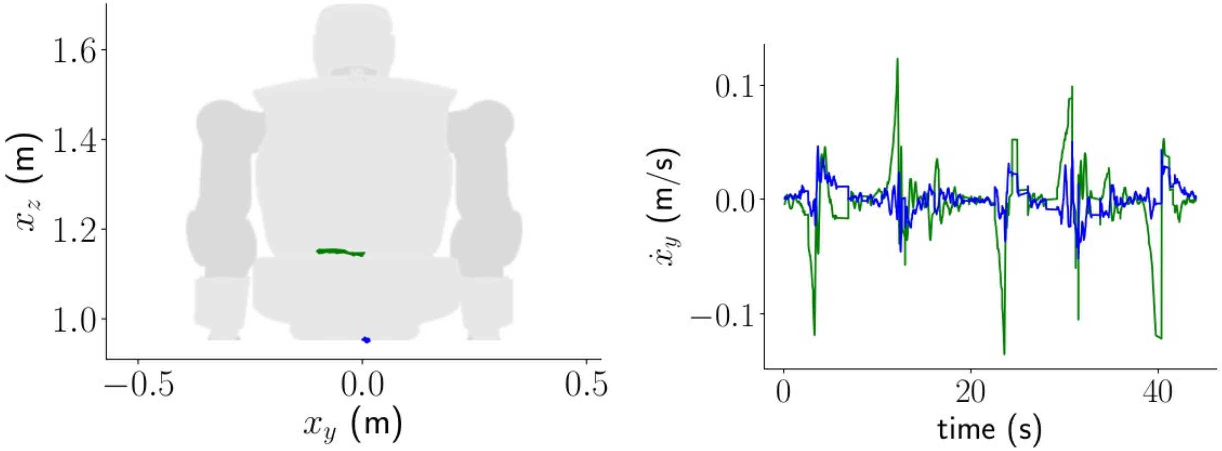




State Estimation: Results



(a) Feet flat on the ground



(b) Feet flat on a balancing board

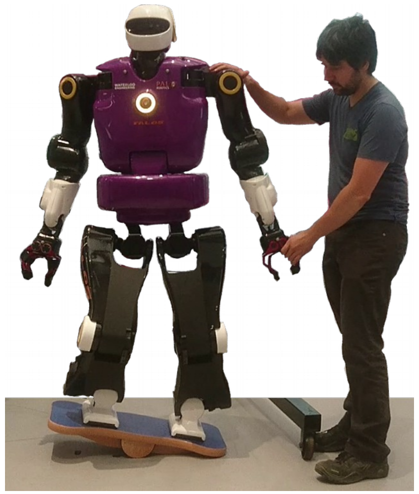
Applications

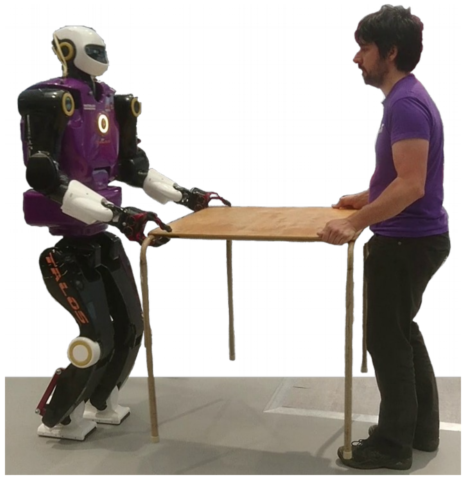
Balancing
- Also on balancing board

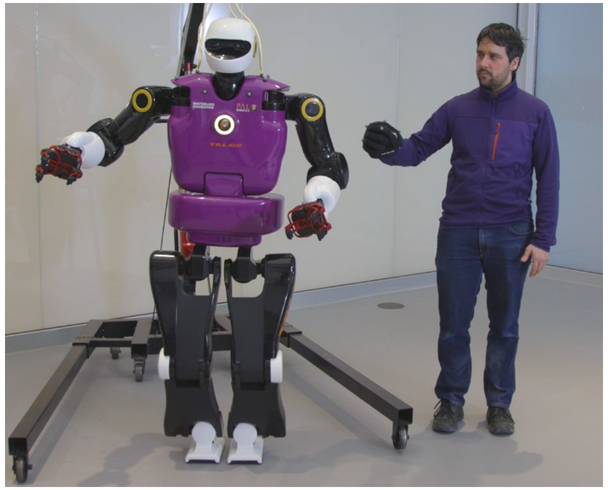
Collaborative Table Carrying
- with PAL walking controller
- Joint impedance control for arms and torso

Kinesthetic teaching
- Joint impedance control
- With Passivity-based WBC

Teleoperation
- Using PAL WBC
- With external tracking system







Research Directions

- Dynamic stepping
- Comparison Passivity-based vs. Inverse Dynamics
- Step recovery/Walking
- Walking with optimal control results

Interested in Tools:

- Simulation (Gazebo)
- Motion Planning
- Locomotion
- ...

If necessary:

- Control of elastic structures
- Joint torque control

Tutorial (postponed)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