Experiences on maturing Whole-Body Operational Space Control and implementing it into agile bipedal systems

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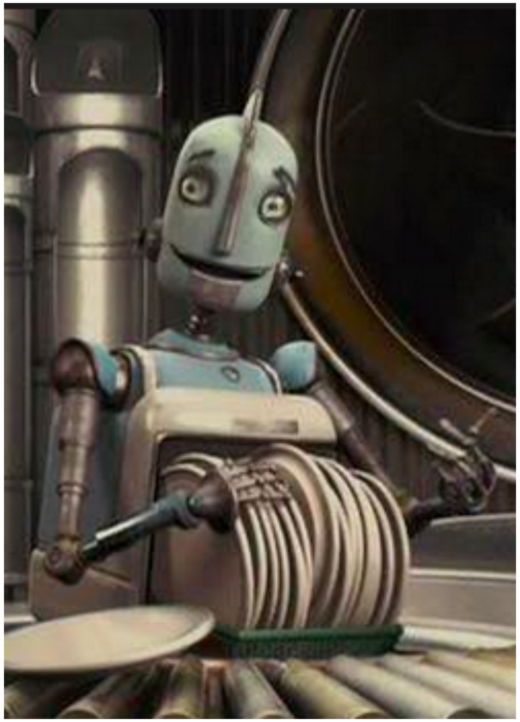
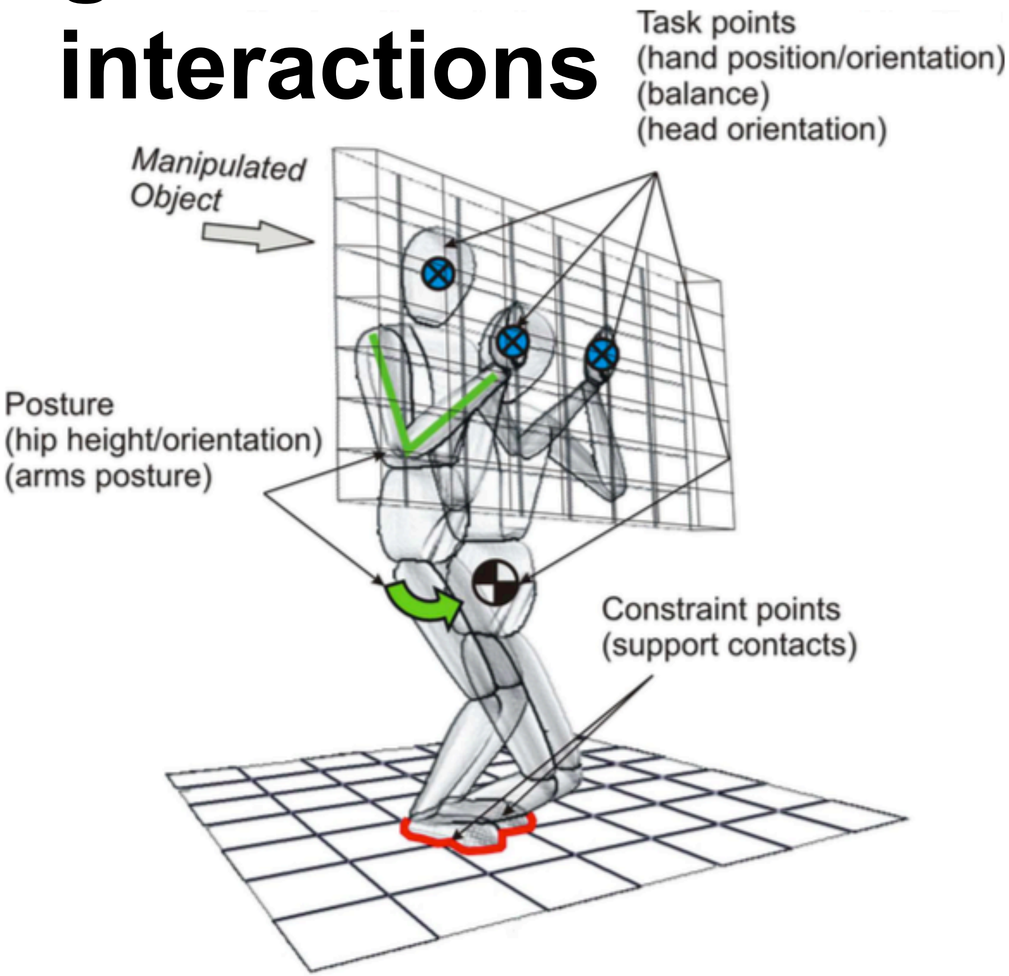
It’s more than manipulation and locomotion

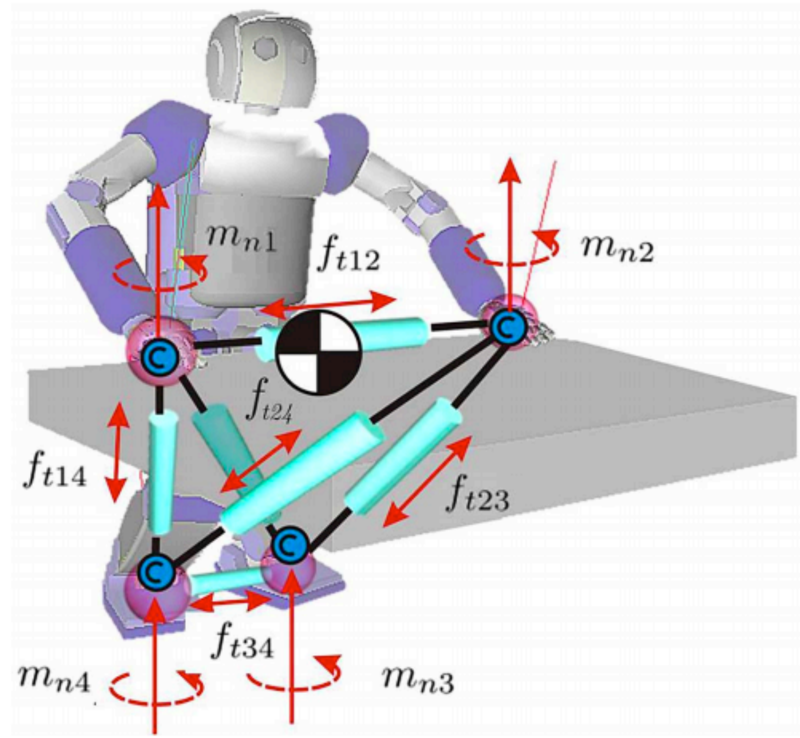
It’s about machines and bionic systems with many degrees of freedom to assist, augment, or represent humans in any way that will increase social comfort, productivity, security and health



Previous work on coordination and generation of movement and force interactions (WBOSC)

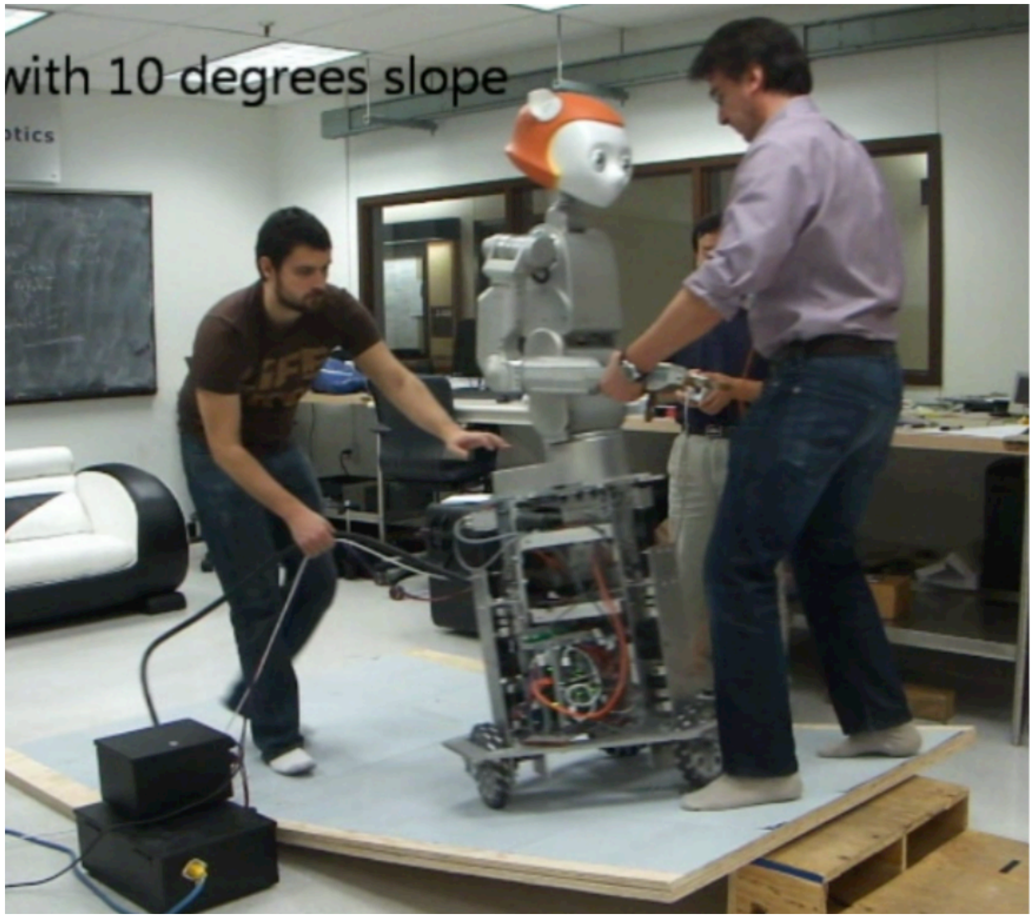


Whole-Body Control of Humanoid Robots (Thesis 2007)



Multicontact / Grasp Model for Humanoid Robots (TRO 2010)

Example: WBOSC for pHRI

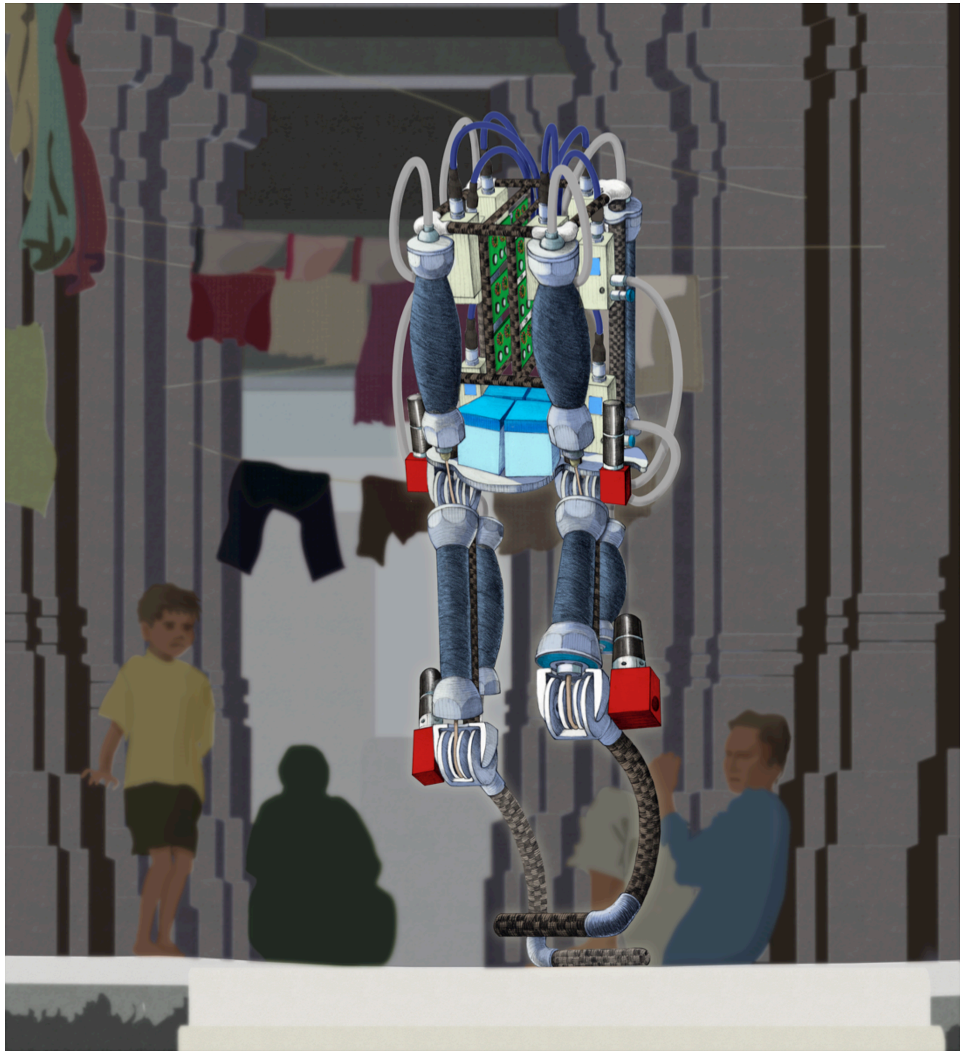


[RSS 2012 Finalist Best Paper Award]
[Autonomous Robots 2013]

WBOSC promises to enable… Physical Human Robot Interaction with Valkyries

Concept art 2014
by The Human Centered Robotics Lab and ZPGraphic

Agile Bipeds Walking on Alley with Kids

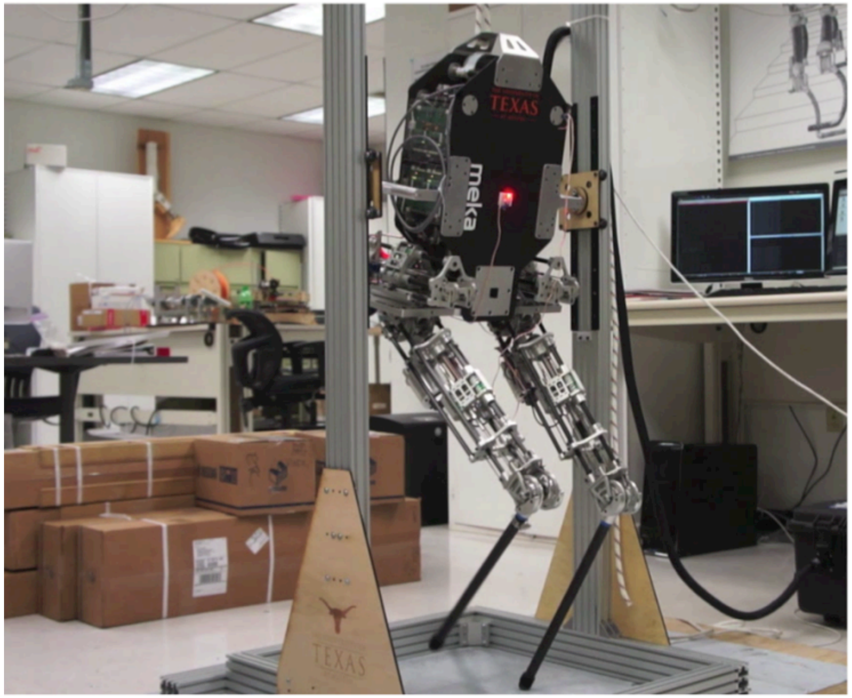


Concept art 2010
by The Human Centered Robotics Lab and ZPGraphic

And safe UGVs in cities

Concept art 2015
by The Human Centered Robotics Lab and ZPGraphic

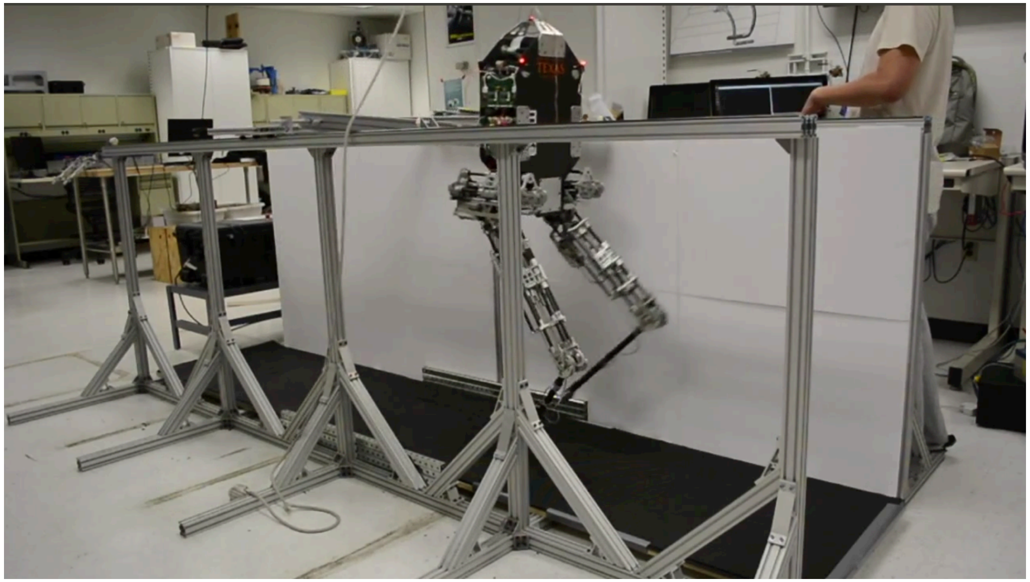
Revolutionary Research . . . Relevant Results



Missing Capabilities on Legged Mobility

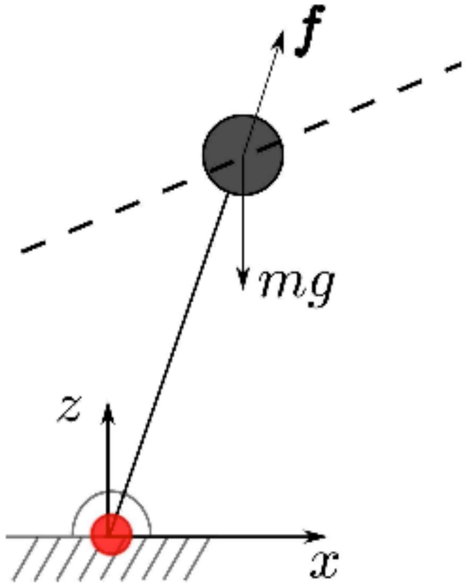
- We lack a general feedback control and planning framework that is not specialized to one type of agility
- We also lack agile hardware platforms on which we can evaluate many types of behaviors.
- We lack realtime plug and play control middleware

In our research we use the Hume hardware

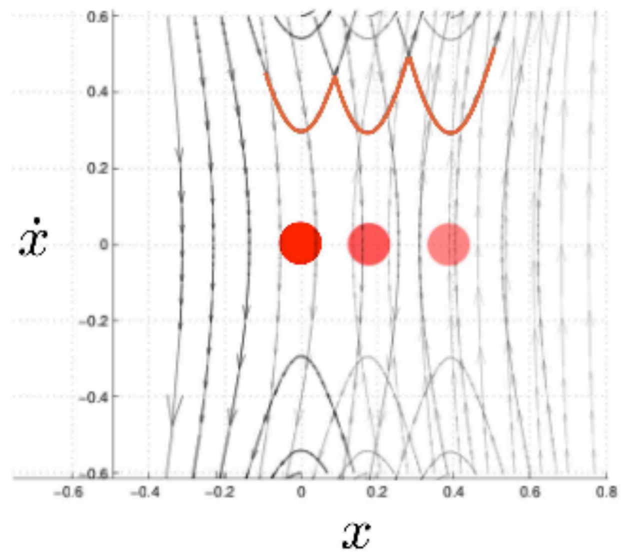


- 6 SEA actuators (15Kg)
- 15 rad/s max velocity
- Removable planarizer
- Feet contact sensors
- Microstrain IMU
- Phase Space Motion capture system
- RTAI LINUX OS
- SrLib Physics Based Simulation

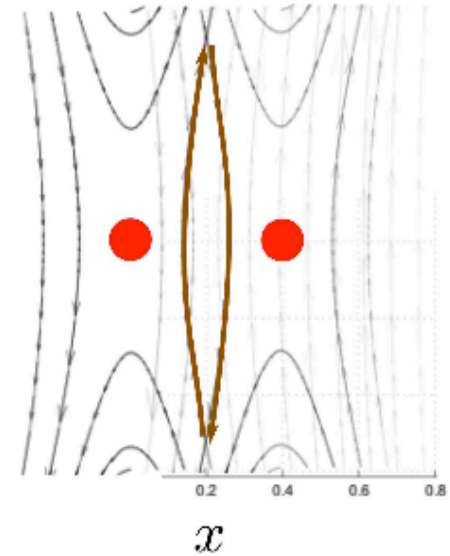
Rely on Prismatic Inverted Pendulum Dynamics



PIPM Model



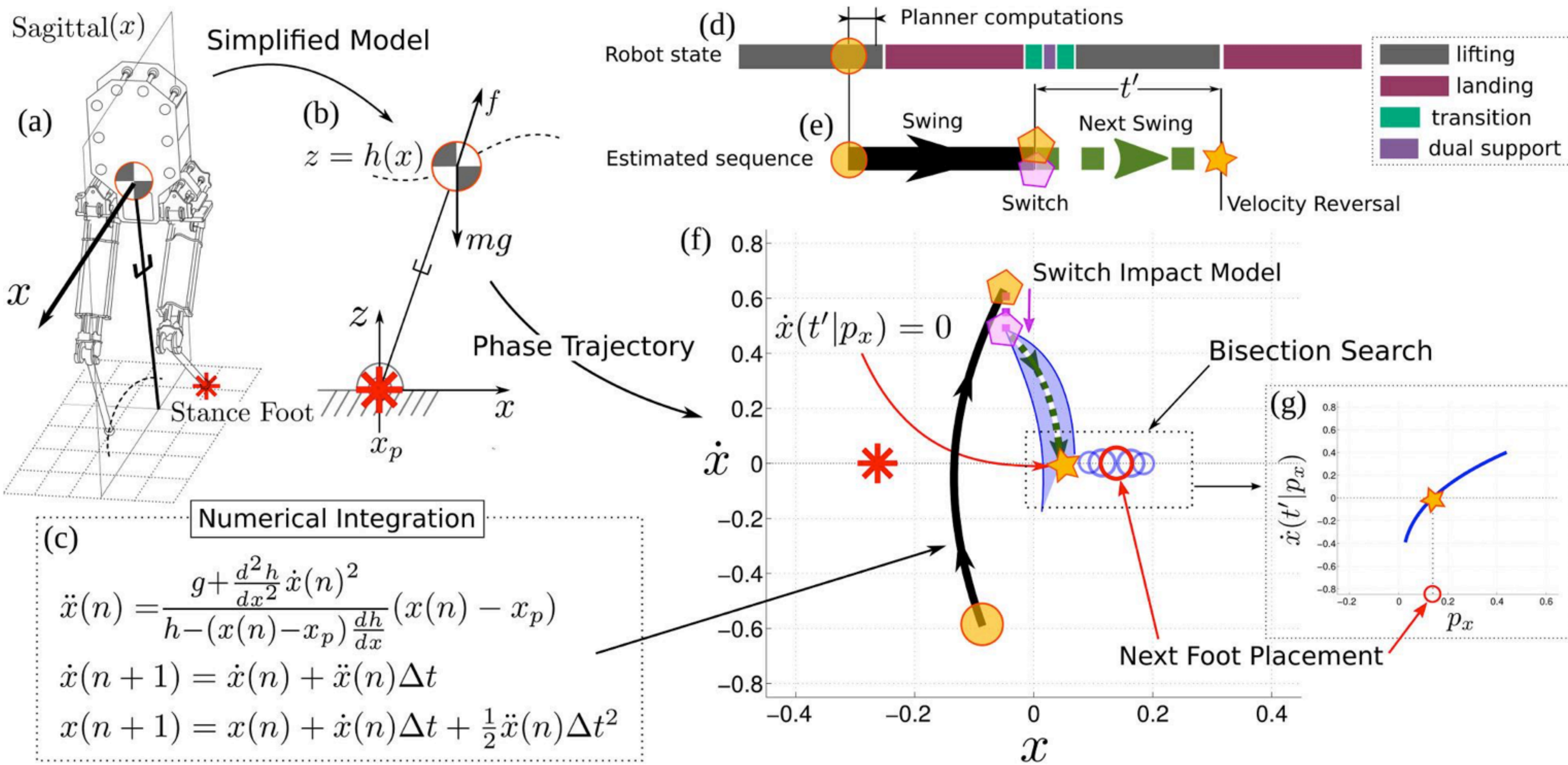
(a) Progressive Step



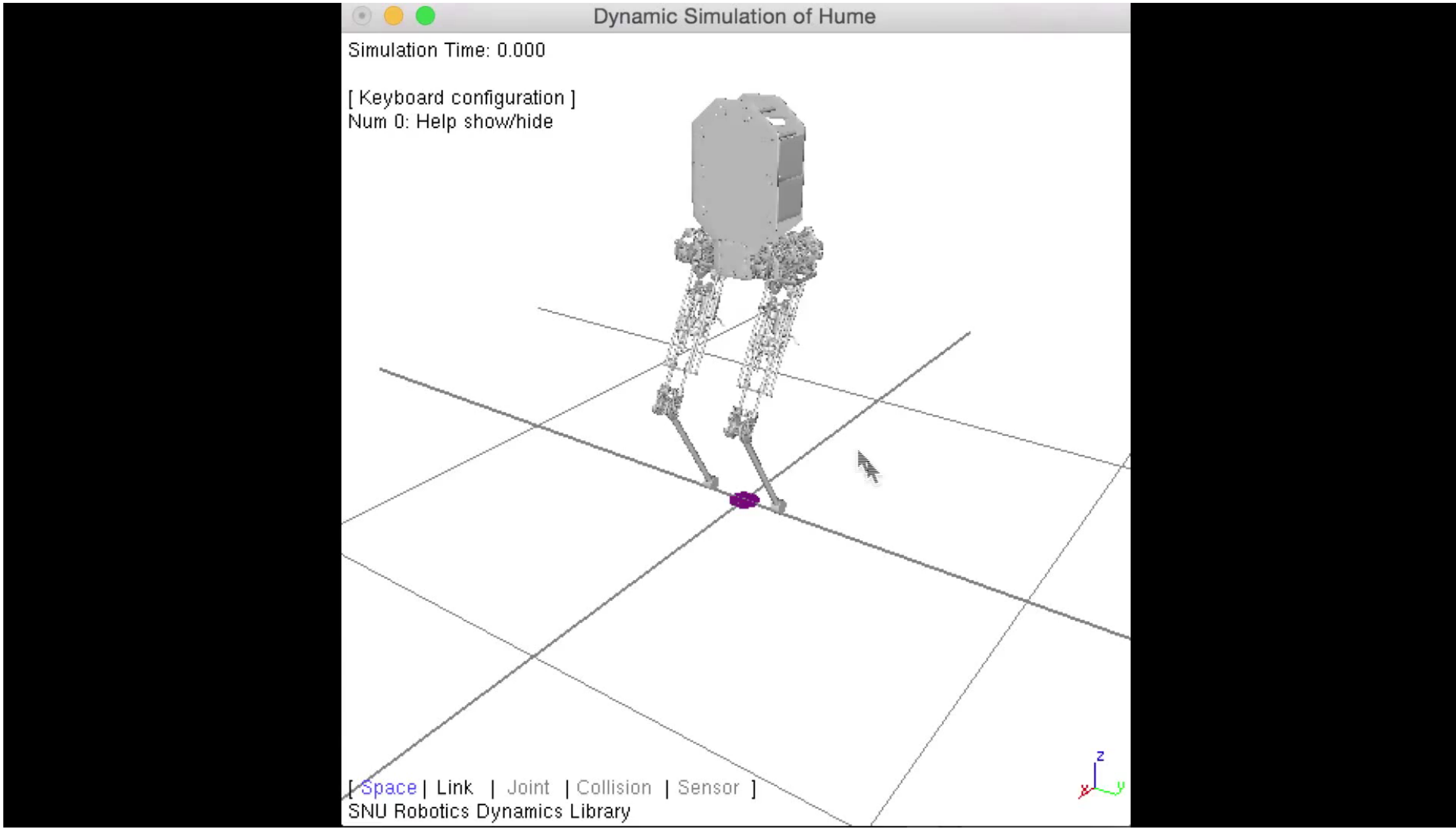
(b) Cyclic step

$$\ddot{x} = \frac{g + \frac{d^2 z}{dx^2}\dot{x}^2}{z - (x - x_p)\frac{dz}{dx}}(x - x_p)$$

Constant Time to Velocity Reversal Online replanning strategy



Stabilizing Properties

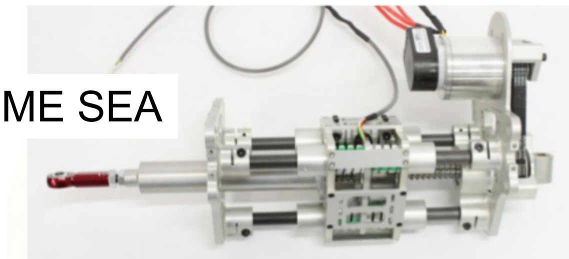


Validating Whole-Body Operational Space Control on Bipeds

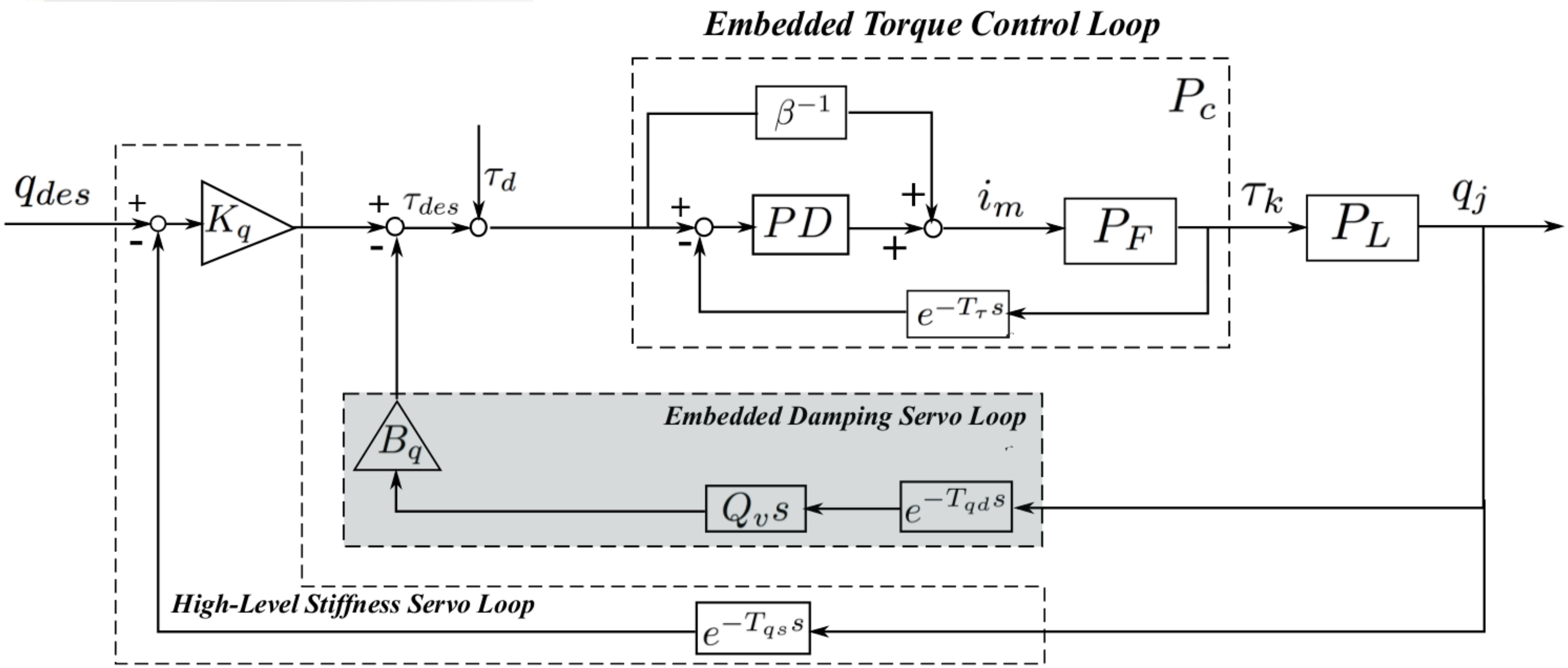
Technology:	Method:
Online foot placement planning	Phase space planning
Online robust re-planning	Continuous planner update
Accurate body pose estimation	Fusion of inertial and motion capture sensing
Impedance control of series elastic actuators	Distributed controller
Floating base inverse dynamic for foot and body control	Whole-body compliant control
Multicontact models for dual contact phases	Multicontact / grasp matrix
Smooth transition between contact states	Impedance control

High Impedance Control of SEAs

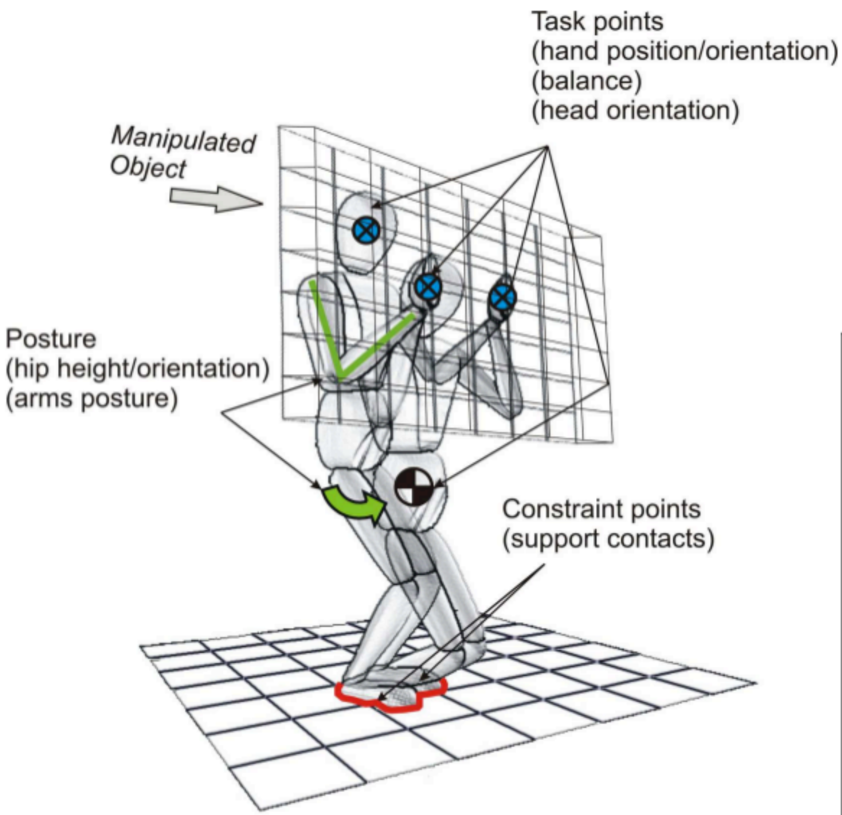
HUME SEA



[Under Journal Review 2015]
[Humanoids 2014]



Additionally, when using WBC algos another problem is the big math



$A_1 \leftarrow A$ and $b_1 \leftarrow b$

for $i = 1 : n$ do

$$\underset{\mathcal{X}}{\text{minimize}} \quad \pi_i = \|E_i \mathcal{X} - u_i\|^2$$

$$\text{subject to} \quad A_i \mathcal{X} = b_i$$

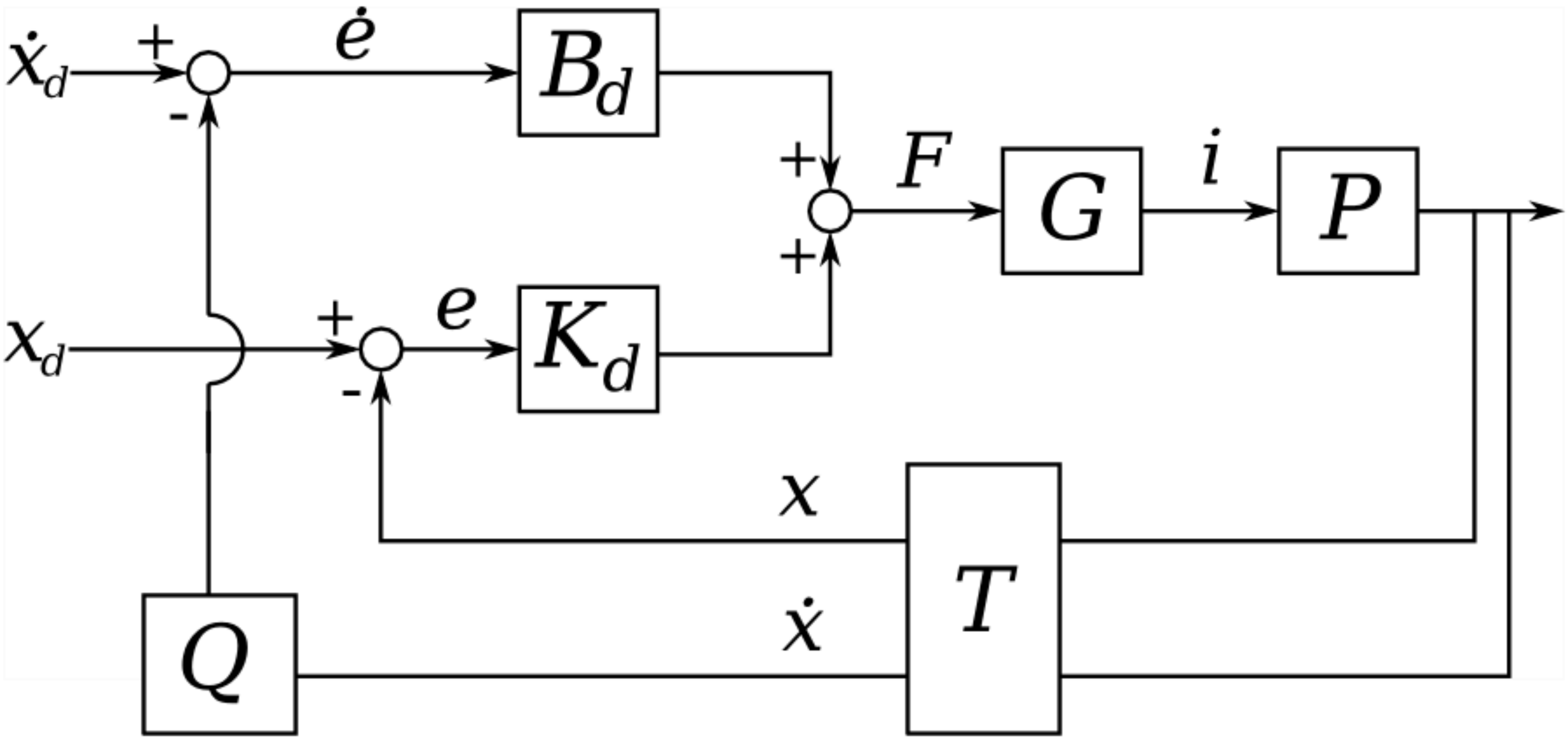
$$G \mathcal{X} \preceq h$$

$$A_{i+1} \leftarrow [A_i^T \; E_i^T]^T$$

$$b_{i+1} \leftarrow [b_i^T \, E_i \, \mathcal{X}^T]^T$$

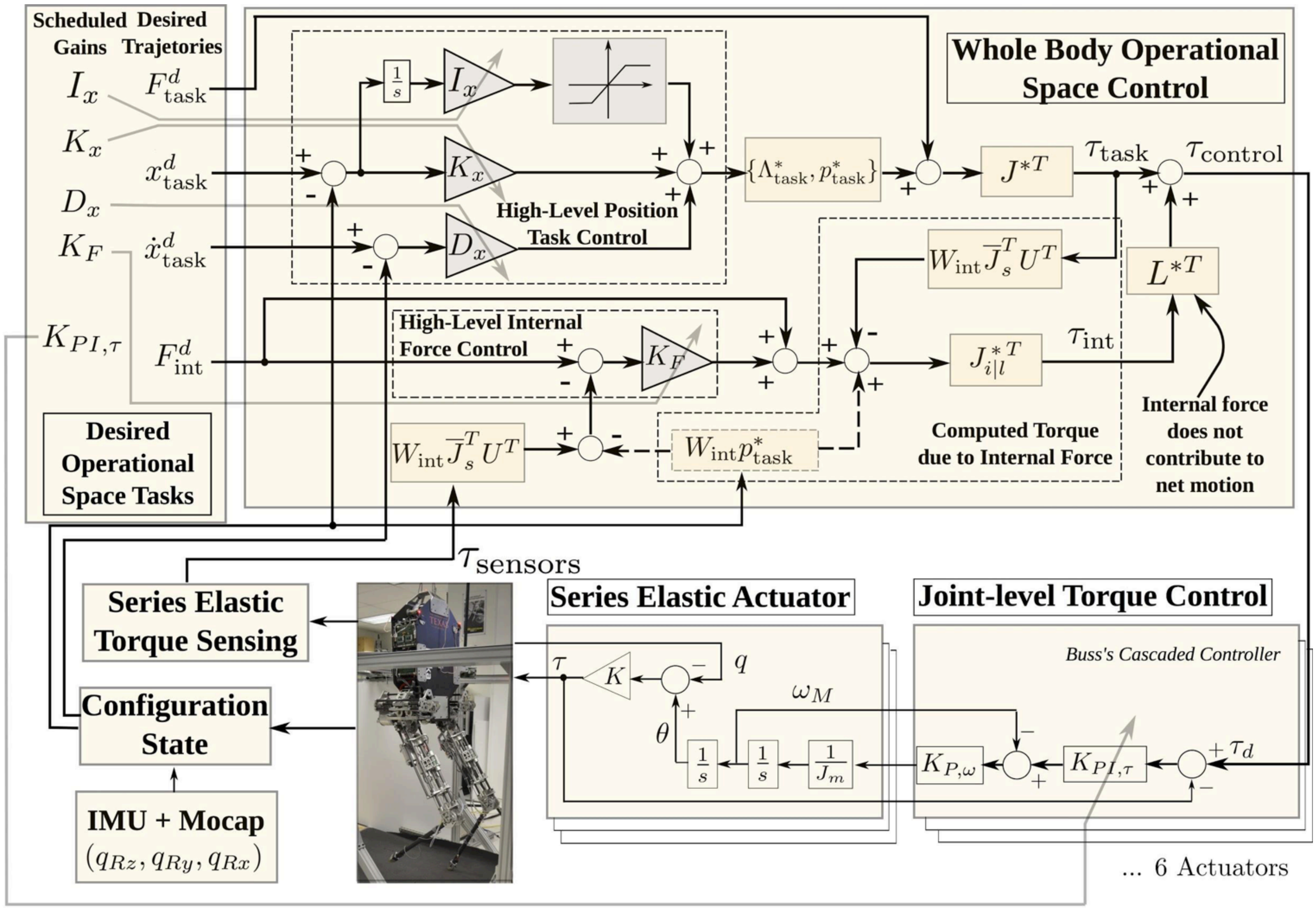
end

Latencies and Noise



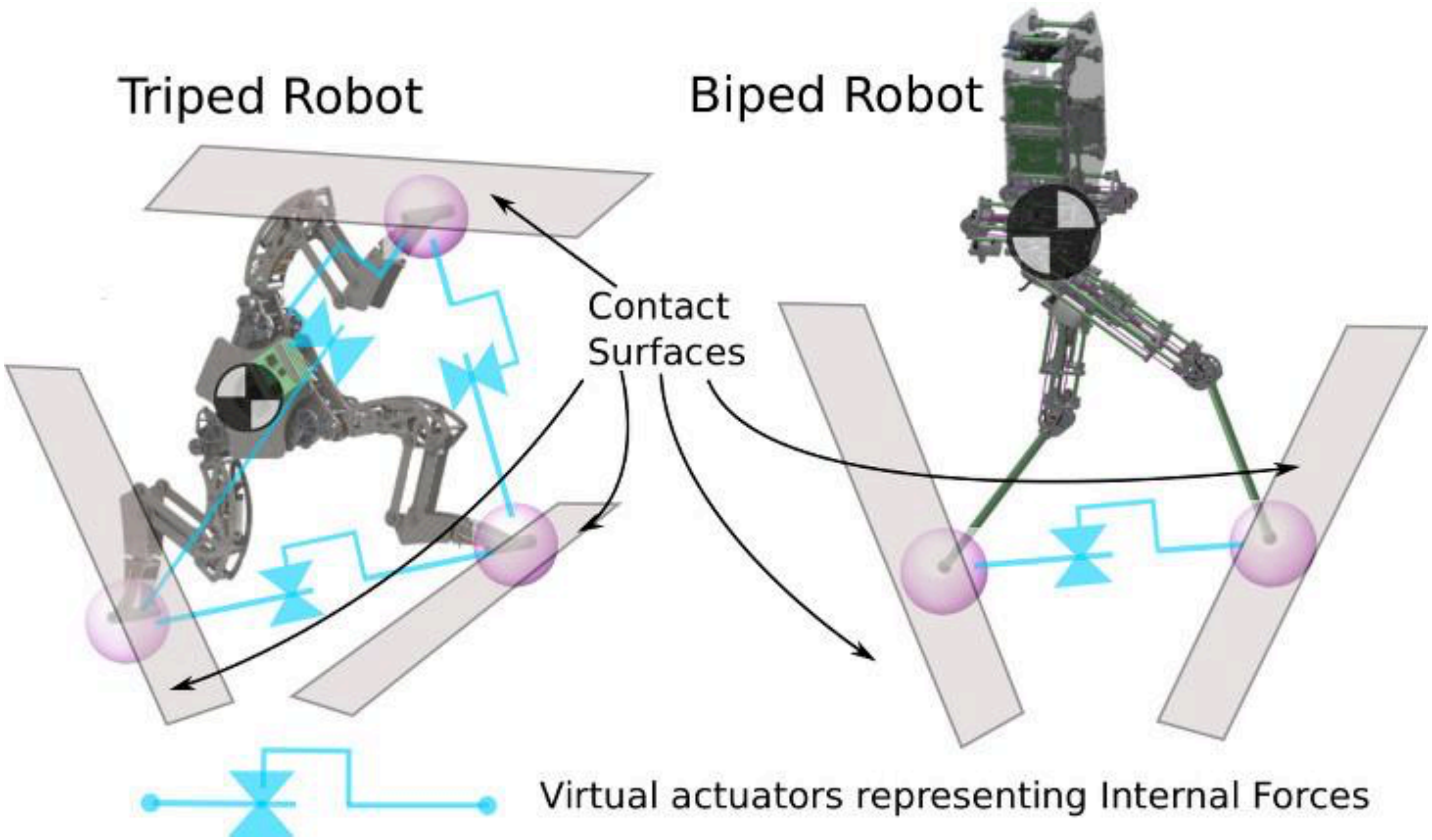
Stability

Hume Version of WBOSC

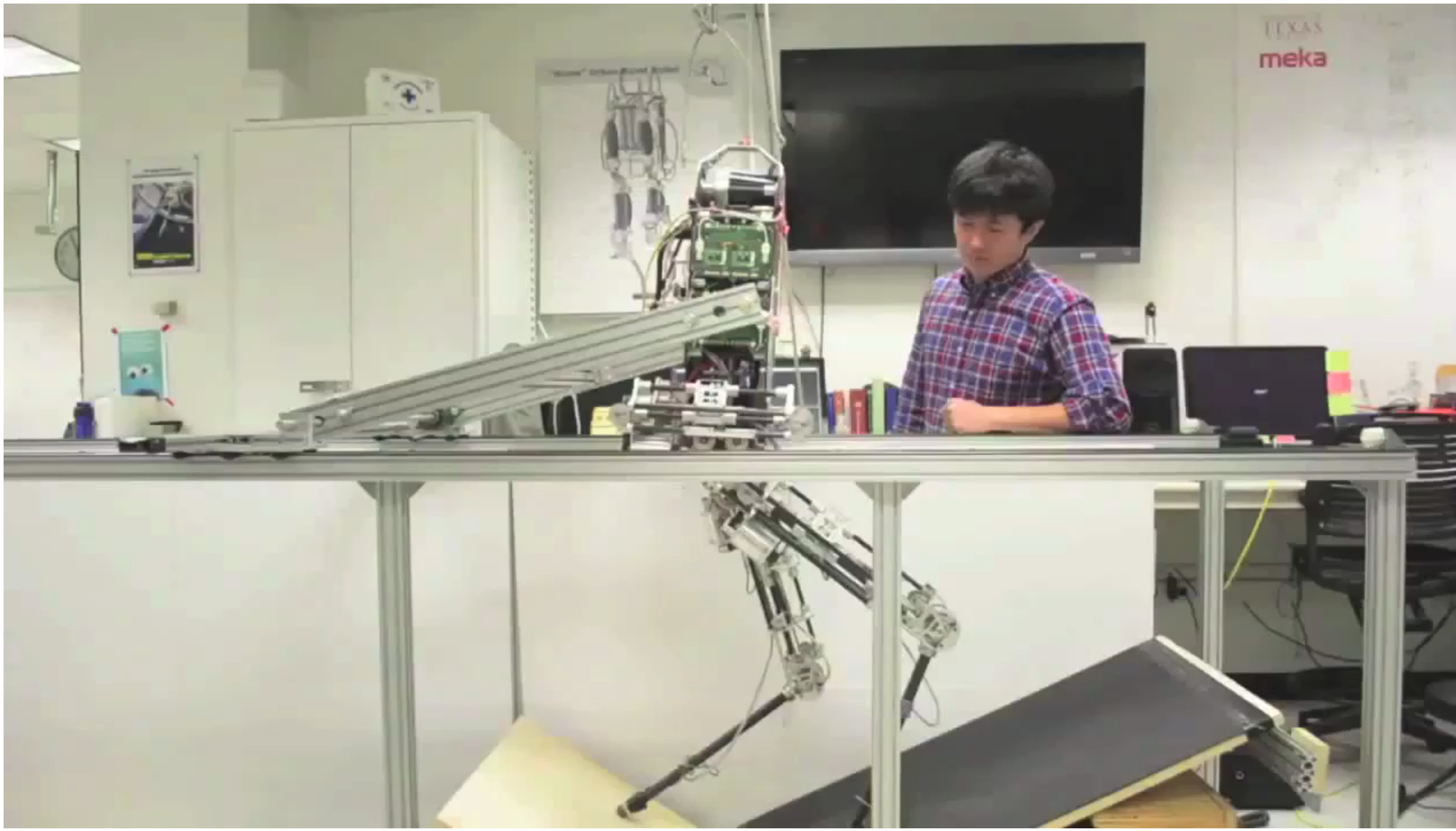


Multicontact mobility is as important as locomotion

Idea of Internal Forces in Point Foot Robots



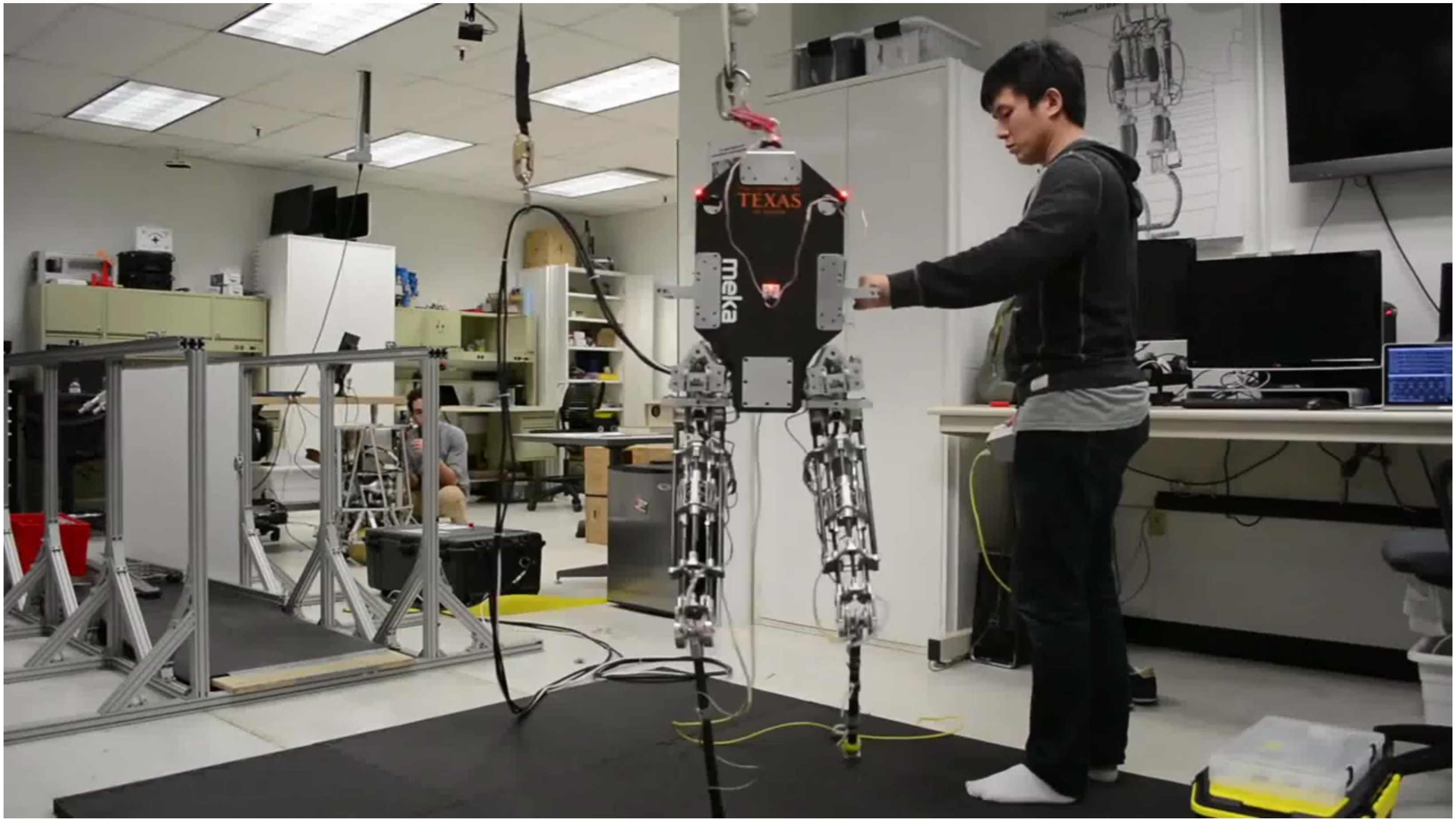
Whole-Body Control with Disturbances



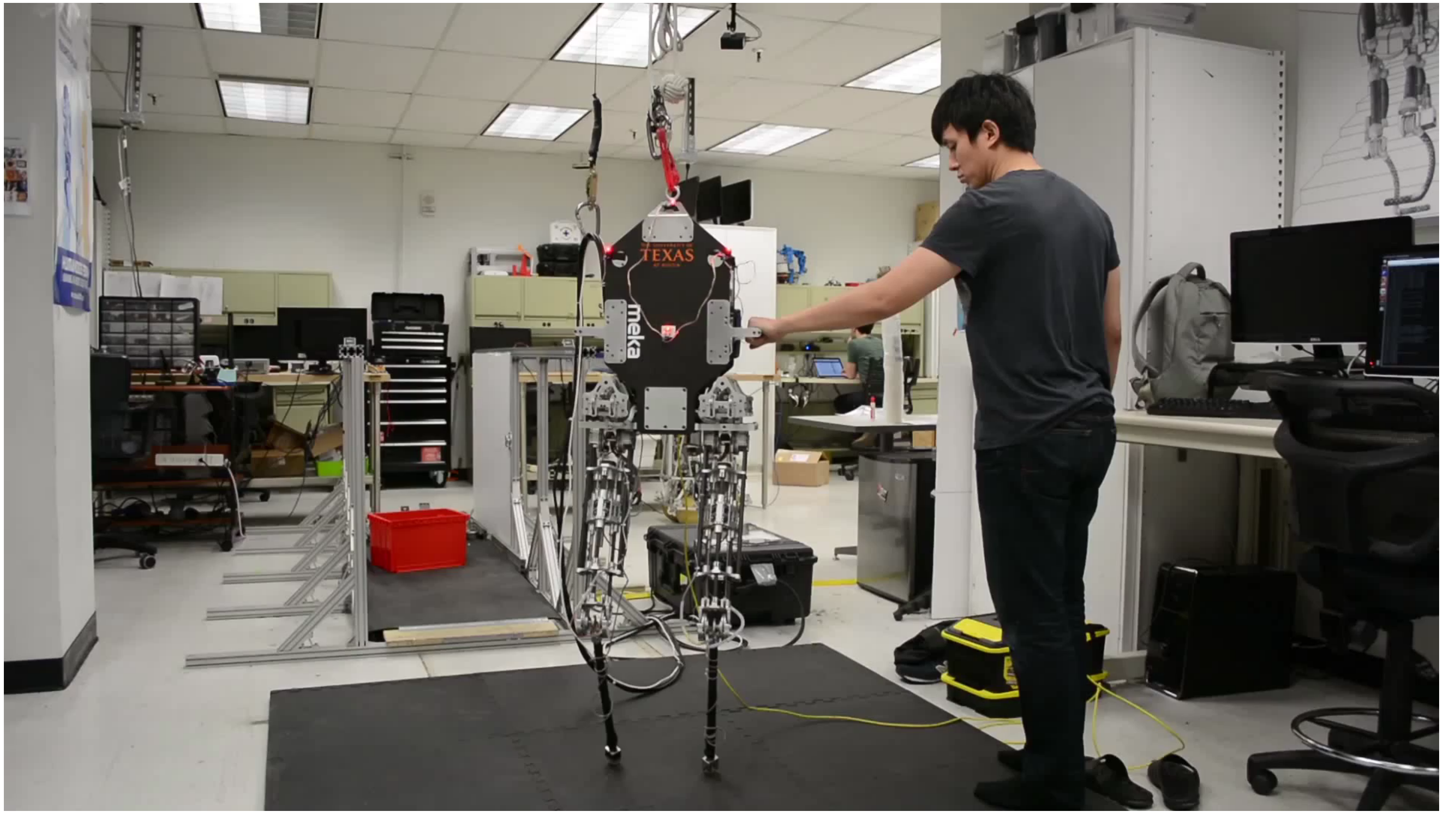
[Submitted for Journal Publication 2015]

Locomotion with whole-body control

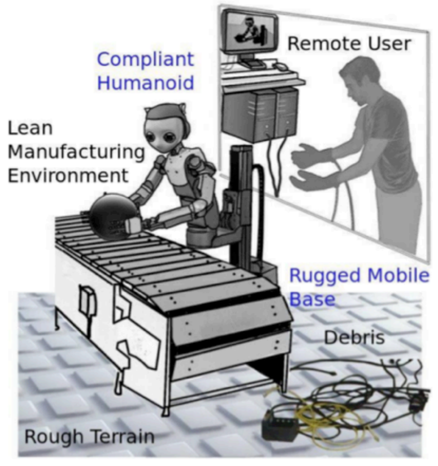
Starting to test untethered

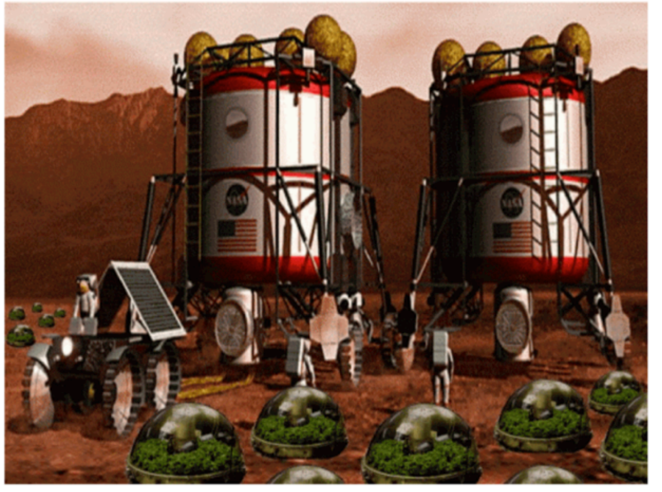


More progress



NRI 2012-2016

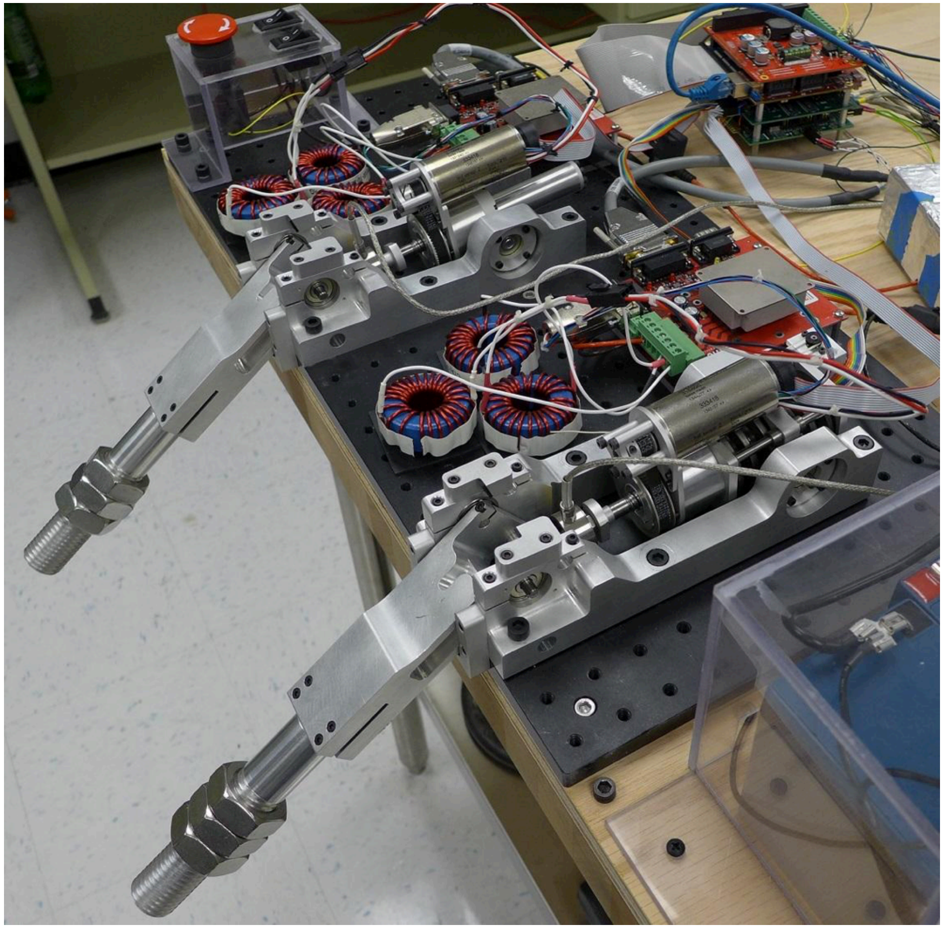




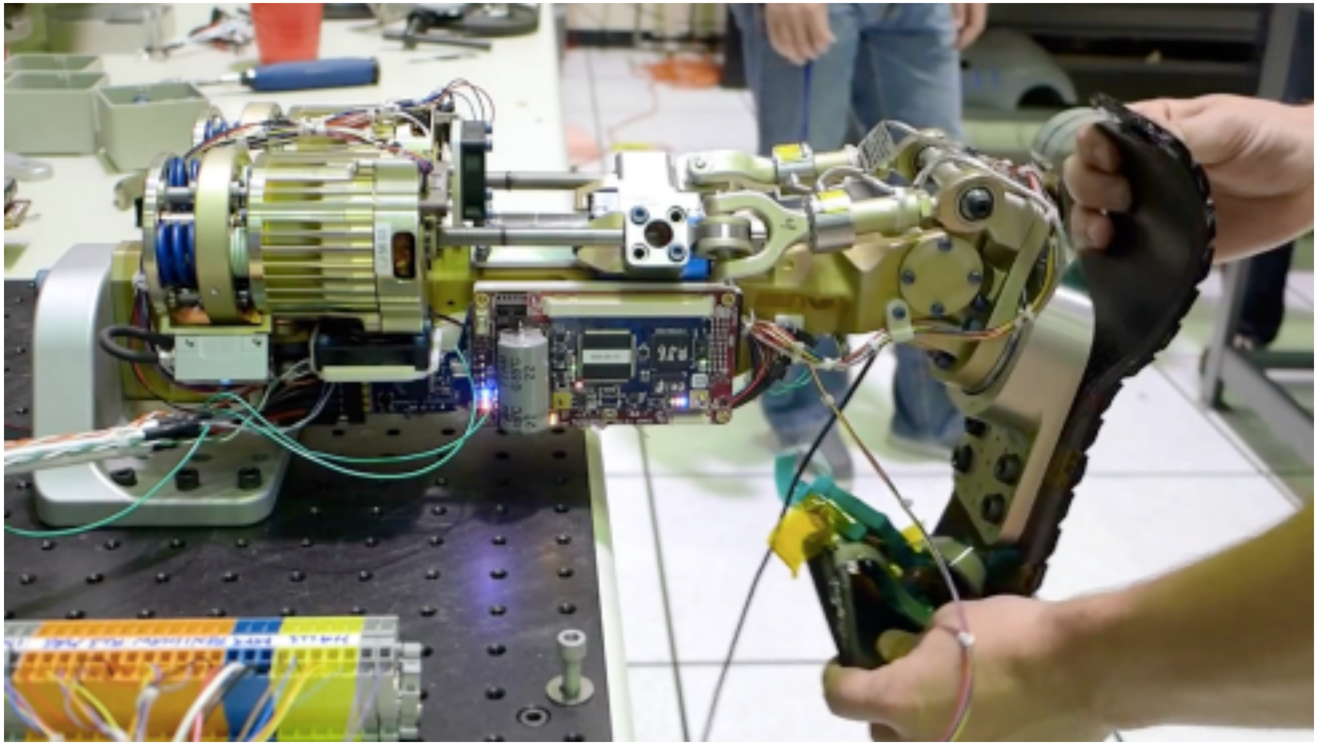
DRC 2012-2013

We Developed Mechanics

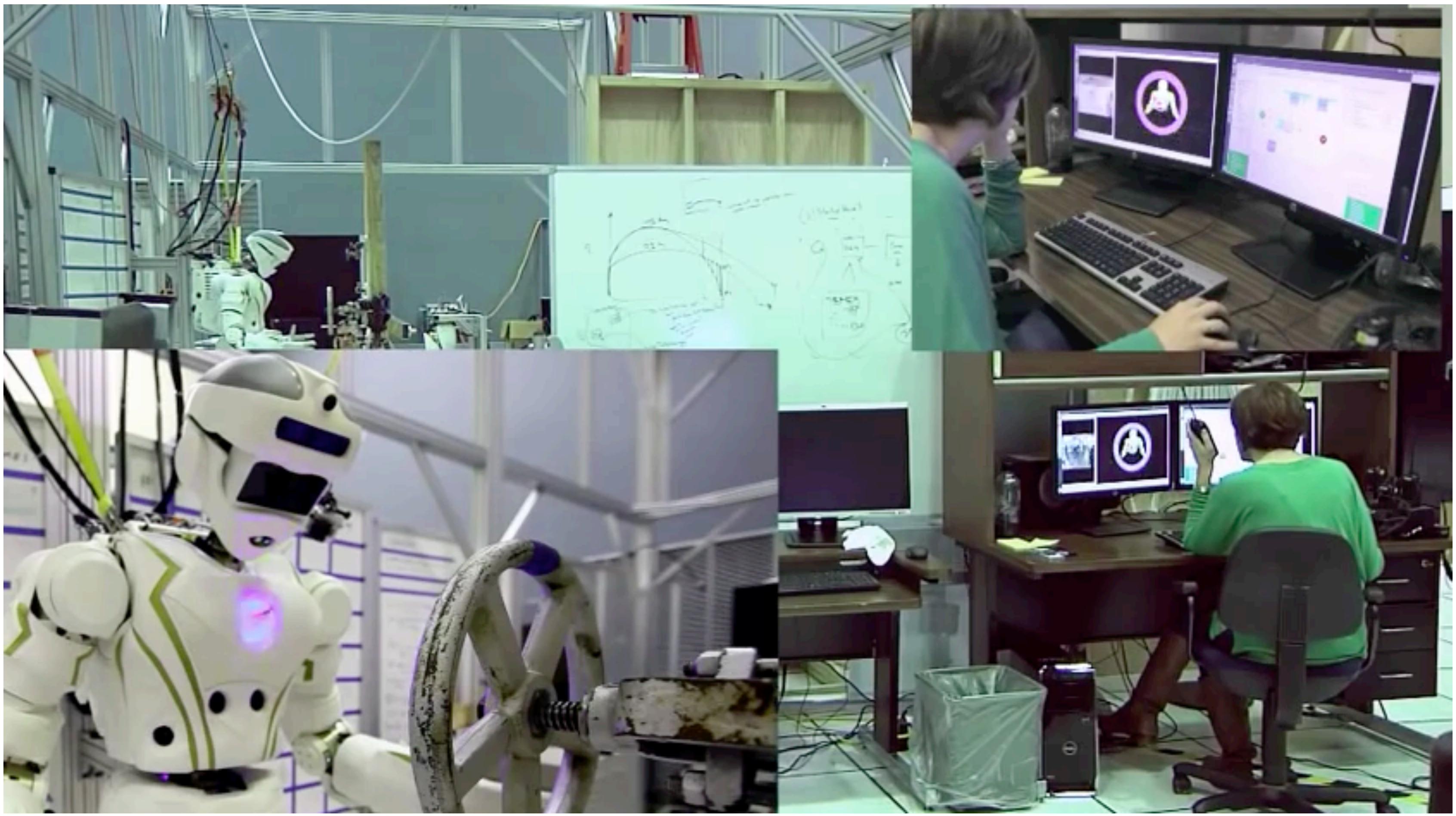
[IEEE TMECH 2014]



Experiences Developing Valkyrie



We Integrated WBOSC on Valkyrie



ControlIt! Middleware for Whole-Body Operational Space Control

Property	UTA-WBC	ControlIt!
OS	Ubuntu 10.04	Ubuntu 12.04 / 14.04
ROS Integration	ROS Fuerte	ROS Hydro and ROS Indigo
Linear Algebra Library	Eigen2	Eigen3
Model Library	Tao	RBDL 2.3.2
Model Description Format	Proprietary XML	URDF
Integration (higher levels)	N/A	Parameter binding
Integration (lower levels)	Proprietary	Robot Interface and Clock plugins
Controller Introspection	Parameter Reflection	Parameter Reflection + ROS Services
WBC Configuration	YAML	YAML / ROS Parameter server
WBC Reconfiguration	N/A	Enable / disable tasks and constraints
Key Abstractions	Task, constraint, skill	Compound task, constraint set, sensor set
Task / Constraint Libraries	Yes / statically coded	Yes / dynamic loading via ROS pluginlib
Number of threads	1	3
Simulator	Proprietary	Gazebo 4.0
Website	http://sourceforge.net/projects/stanford-wbc/	https://robotcontrolit.com

Features

WBOSC API: CompoundTask, ConstraintSet, WholeBody Controller
Plugin library: RobotInterface, ServoClock
Multithreaded architecture: ServoThread, ModelUpdater, TaskUpdater

Video

ControlIt!: A Middleware for Whole-Body Operational Space Control

Complementary Video

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