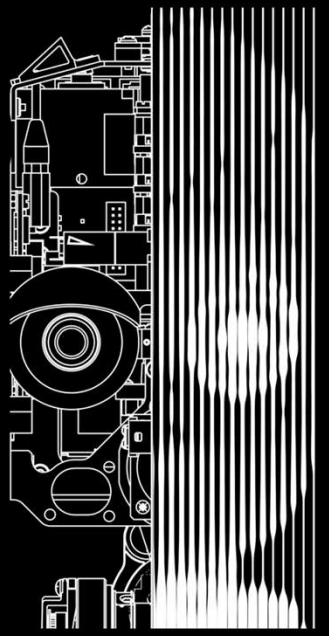
ISTITUTO ITALIANO
DI TECNOLOGIA
ARTIFICIAL AND MECHANICAL
INTELLIGENCE

Bringing the iCub Humanoid Towards Real-World Applications

Daniele Pucci



The population aged 65 years or more in EU will reach 129.8 million by 2050. Source

In Europe, chronic RMDs affect more than 120 million[1].
3.3% European GDP spent on occupational injuries[2]
Source-[1], Source-[2]

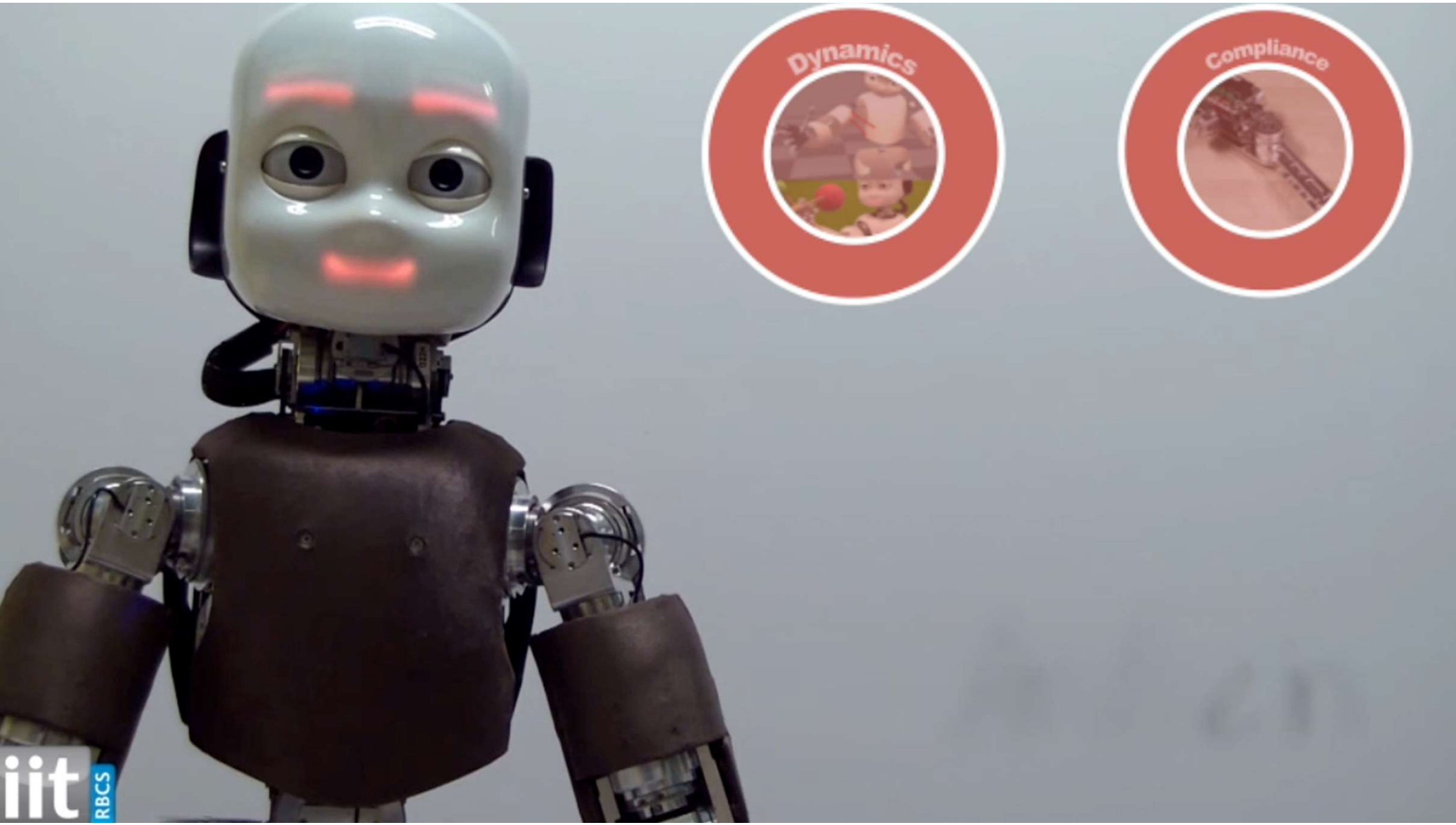
Natural disasters kill on average 45,000 people per year, globally
Source

On April 3rd 2020, more than 3.9 billion people, or half of the world's population, have been asked/ordered to stay at home.
Source

Develop new tools,
in the form of humanoids

WUHAN
CHINA

… starting from iCub


Dynamics
Compliance
iit
RBCS

Our Missions

ami.iit.it

github.com/ami-iit

1. Evolve iCub for real applications: research on Embodied AI

2. Technology transfer from research to companies

DANIELI

INAIL
ISTITUTO NAZIONALE PER L'ASSICURAZIONE CONTRO GLI INFORTUNI SUL LAVORO

HONDA

CAMOZZI

CLASSIFIED

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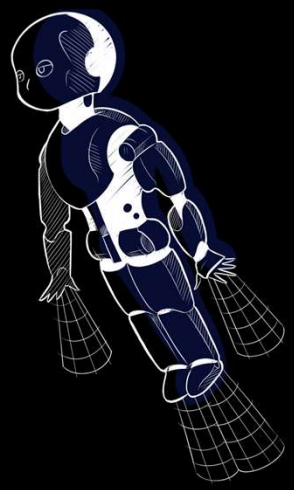
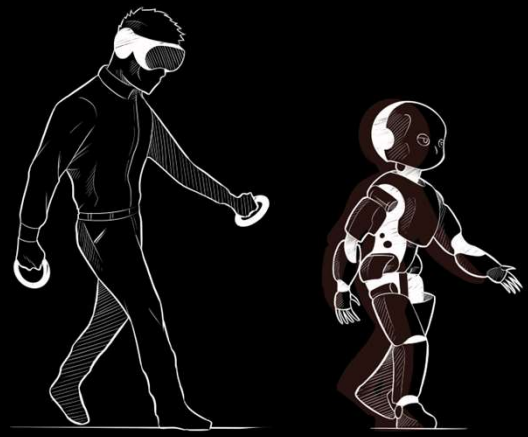
1. Evolve iCub for real applications: research on Embodied AI

Human-Robot Collaboration



Aerial Humanoid Robotics



Avatar Systems

Our Missions

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1. Evolve iCub for real applications: research on Embodied AI

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1. Evolve iCub for real applications: research on Embodied AI

Why and When MathWorks Tools?

1. Lower barriers for non-expert coders

2. Fast analysis, rapid prototyping and deployment

How to evolve iCub towards applications?

$$M(q,\pi)\dot{\nu} + C(q,\nu,\pi)\nu + g(q,\pi) = J^\top F_{\text{muscle}} + J^\top F_{\text{ext}}$$

$q \in SE(3) \times \mathbb{R}^n$ π : Body and muscle parameters $\nu \in se(3) \times \mathbb{R}^n$

Simplified and constrained

github.com/ami-iit/human-model-generator

github.com/ami-iit/mvnx-to-urdf

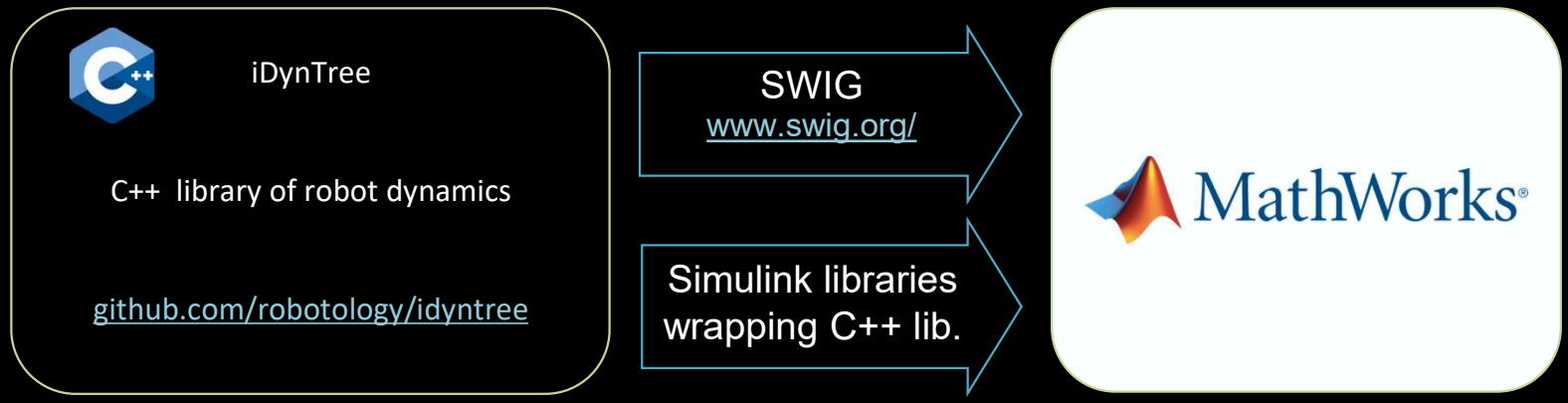
github.com/ami-iit/ADAM

github.com/robotology/idyntree

Robot (/+) Human

$$\dot{x} = f(x,u,\pi)$$
$$0 = g(x,\pi)$$

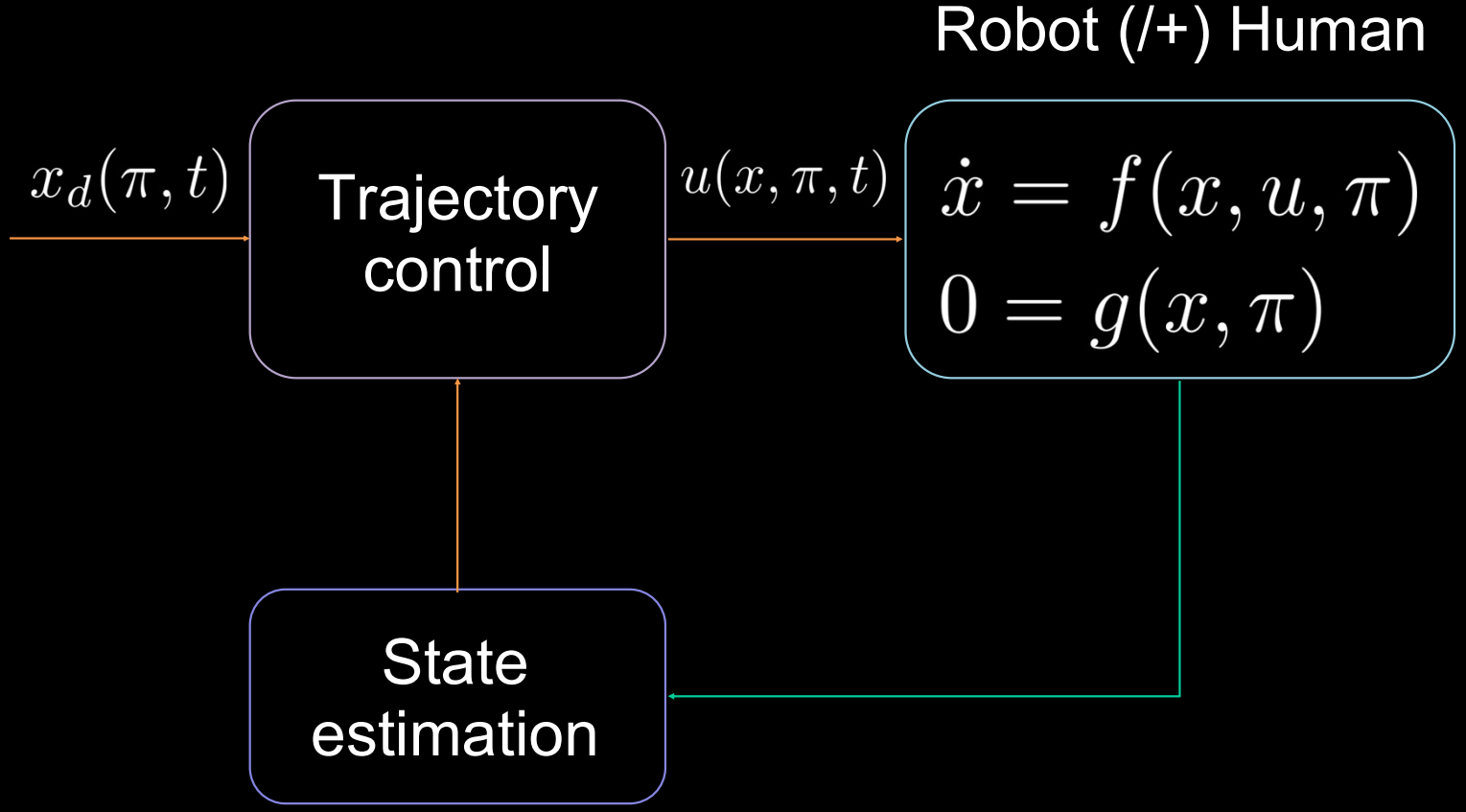
From C++ to Matlab & Simulink



Simulink libraries that wrap C++ libraries

- **BlockFactory**: A tiny framework to wrap algorithms for dataflow programming, including Simulink.
  robotology.github.io/blockfactory
- **WB-Toolbox:** Library that uses BlockFactory to wrap iDynTree functionalities and make them available as Simulink blocks.
  robotology.github.io/wb-toolbox

Simulation and control?



From C++ to Matlab & Simulink

Pure MATLAB/Simulink Libraries

- **matlab-whole-body-simulator:** a simulator for the humanoid robots implemented in Simulink.
  github.com/ami-iit/matlab-whole-body-simulator
- **whole-body-controllers:** Simulink-based whole-body controllers for humanoid robots
  github.com/robotology/whole-body-controllers

2022 Sixth IEEE International Conference on Robotic Computing (IRC)

A Flexible MATLAB/Simulink Simulator for Robotic Floating-base Systems in Contact with the Ground

Nuno Guedelha*†, Venus Pasandi*†, Giuseppe L'Erario*, Silvio Traversaro*, and Daniele Pucci*
* *Artificial and Mechanical Intelligence*, *Istituto Italiano di Tecnologia*, Genova, Italy, firstname.lastname@iit.it
† These two authors contributed equally to this work.

Open Source Robotics-Research Article

INTERNATIONAL JOURNAL OF ADVANCED ROBOTIC SYSTEMS

International Journal of Advanced Robotic Systems
March-April 2020: 1–12

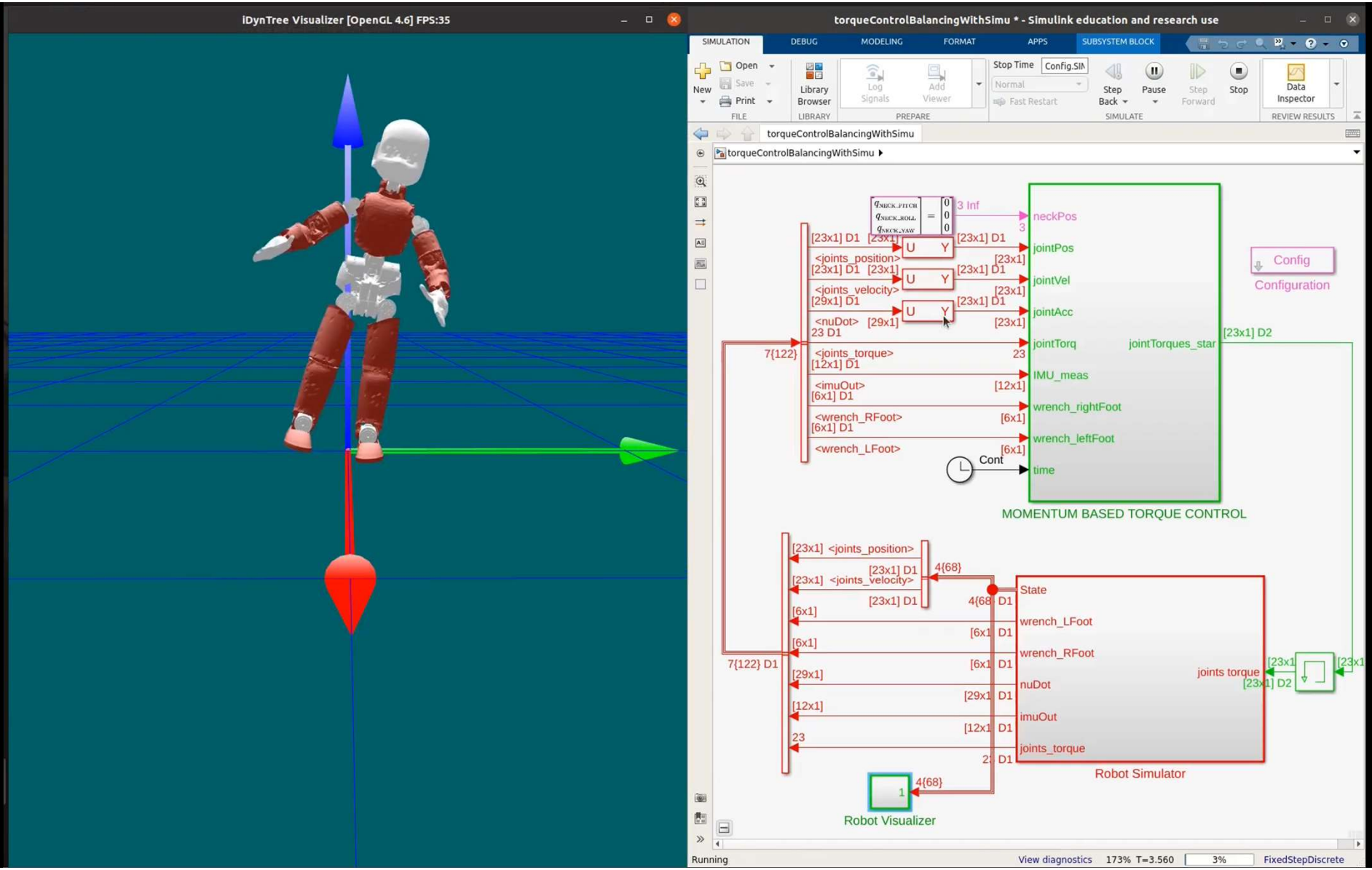
DOI: 10.1177/1729881420921625
journals.sagepub.com/home/arx
SAGE

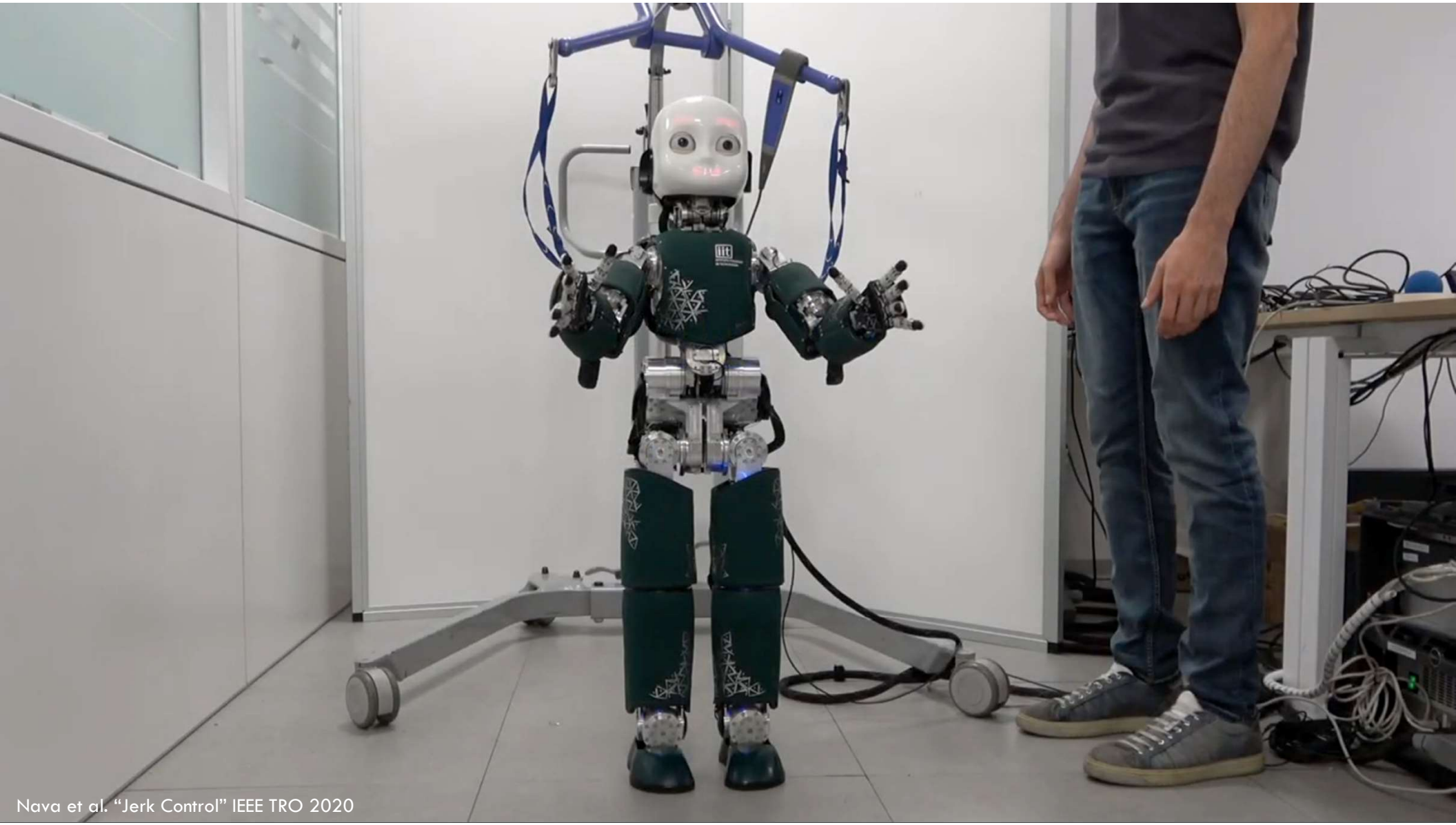
A generic synchronous dataflow architecture to rapidly prototype and deploy robot controllers

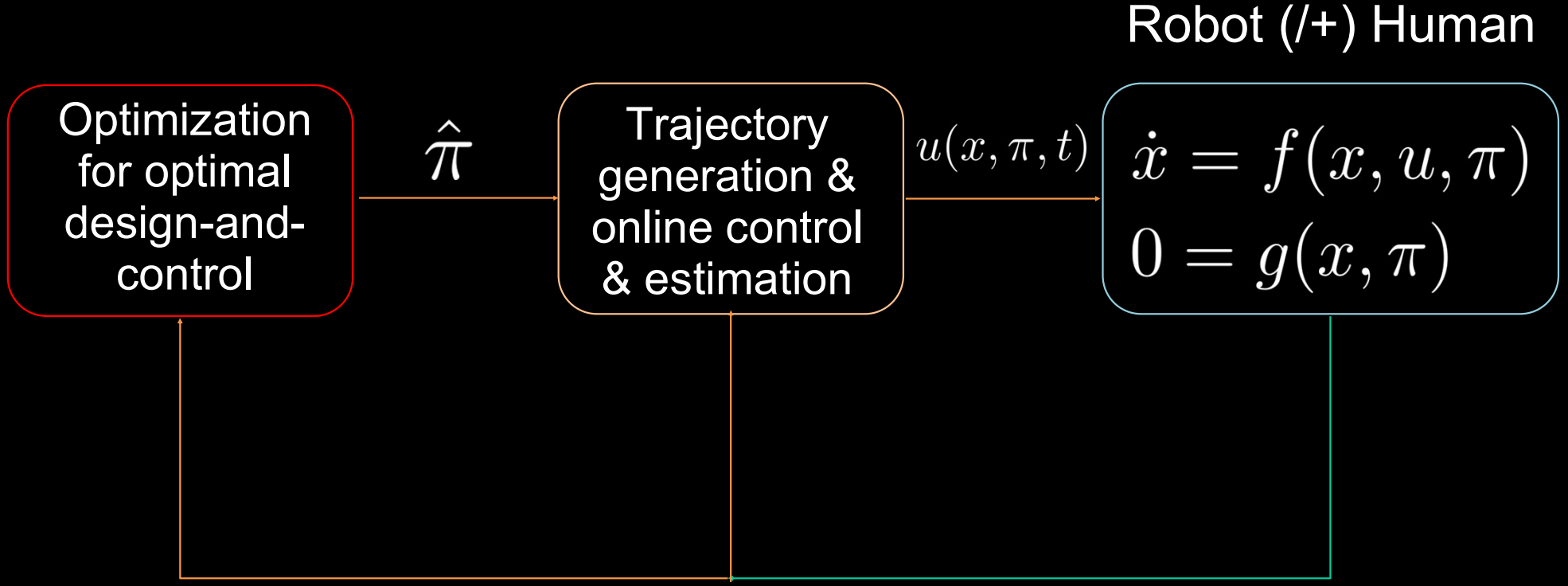
Diego Ferigo[1,2], Silvio Traversaro[1], Francesco Romano[1] and Daniele Pucci[1]

Abstract

The article presents a software architecture to optimize the process of prototyping and deploying robot controllers that are synthesized using model-based design methodologies. The architecture is composed of a framework and a pipeline. Therefore, the contribution of the article is twofold. First, we introduce an open-source actor-oriented framework that abstracts the common robotic uses of middlewares, optimizers, and simulators. Using this framework, we then present a pipeline that implements the model-based design methodology. The components of the proposed framework are generic, and they can be interfaced with any tool supporting model-based design. We demonstrate the effectiveness of the approach describing the application of the resulting synchronous dataflow architecture to the design of a balancing controller for the YARP-based humanoid robot iCub. This example exploits the interfacing with Simulink® and Simulink® Coder™.


iDynTree Visualizer [OpenGL 4.6] FPS:35
torqueControlBalancingWithSimu * - Simulink education and research use
SIMULATION
DEBUG
MODELING
FORMAT
APPS
SUBSYSTEM BLOCK
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Log Signals
Add Viewer
PREPARE
Stop Time
Config.SIM
Normal
Fast Restart
Step Back
Pause
Step Forward
Stop
SIMULATE
Data Inspector
REVIEW RESULTS
torqueControlBalancingWithSimu
neckPos
jointPos
jointVel
jointAcc
jointTorq
jointTorques_star
IMU_meas
wrench_rightFoot
wrench_leftFoot
time
Config
Configuration
MOMENTUM BASED TORQUE CONTROL
State
wrench_LFoot
wrench_RFoot
nuDot
imuOut
joints_torque
joints torque
Robot Simulator
Robot Visualizer
Running
View diagnostics
173% T=3.560
3%
FixedStepDiscrete


Nava et al. “Jerk Control” IEEE TRO 2020



Sartore et al. "Optimization of Humanoid Robot Designs for Human-Robot Ergonomic Payload Lifting" IEEE Humanoids, 2022

ergoCub

New iCub arriving, not in this presentation!

Human-Robot Collaboration

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Prevention by Design?

How to design and control a humanoid robot that perceives humans and minimises thier biomechanical risks?

ergo Cub

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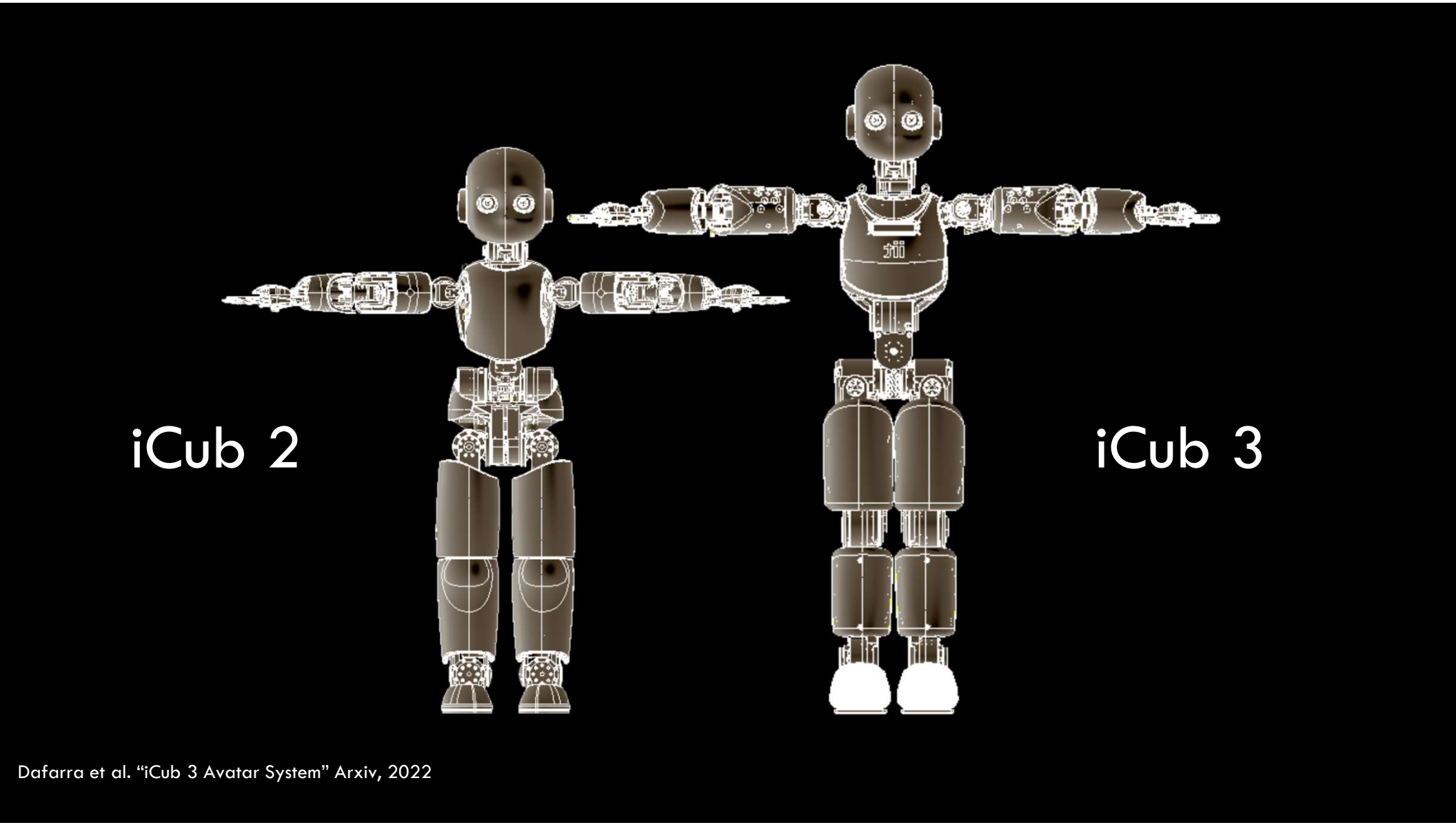
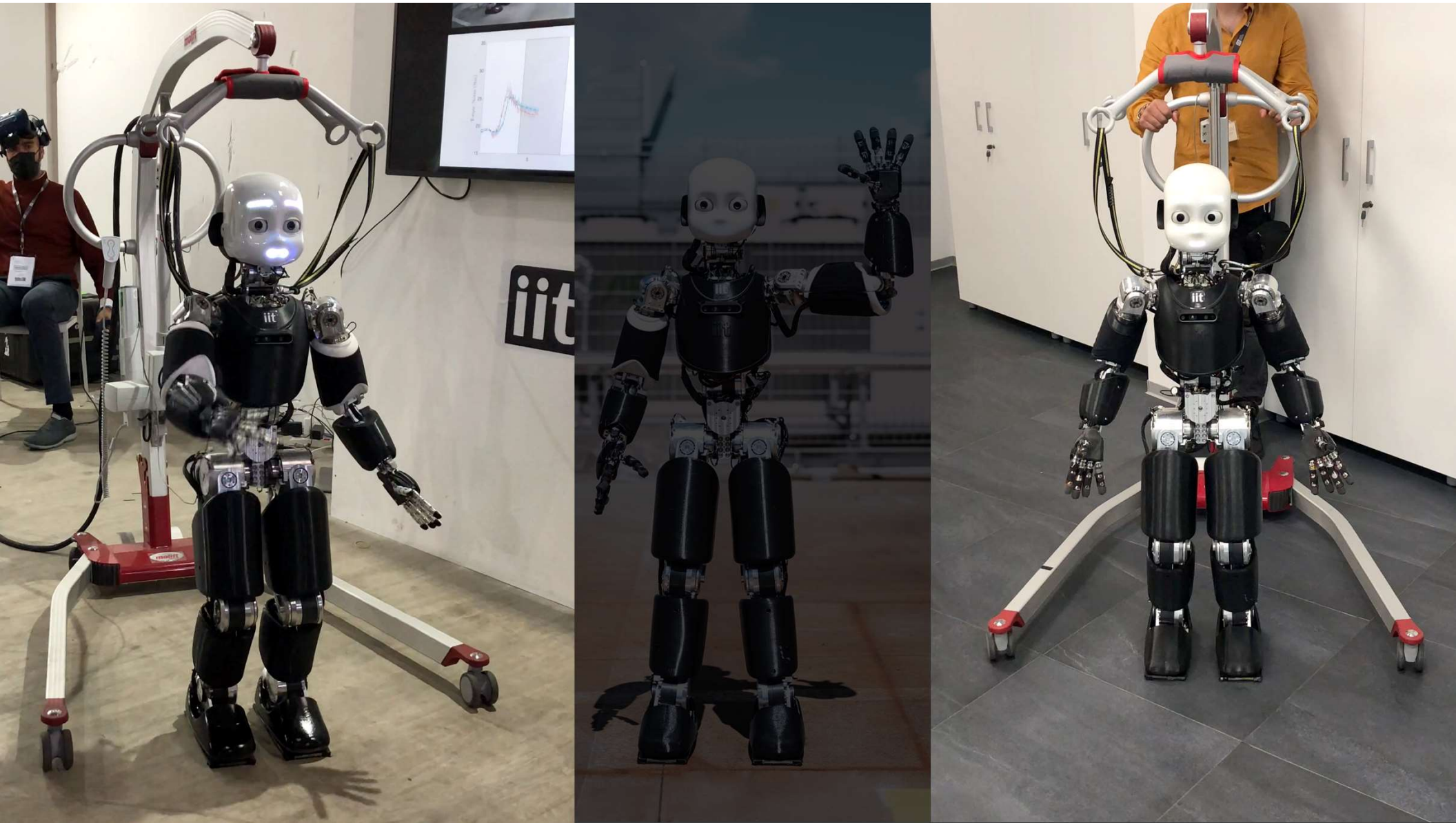
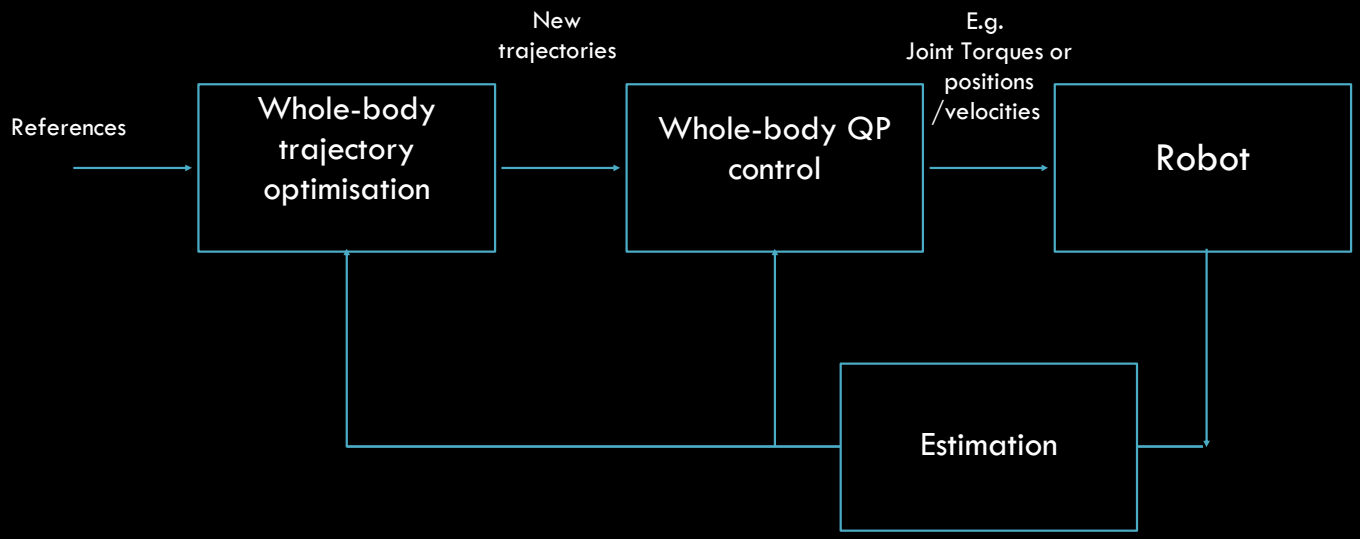


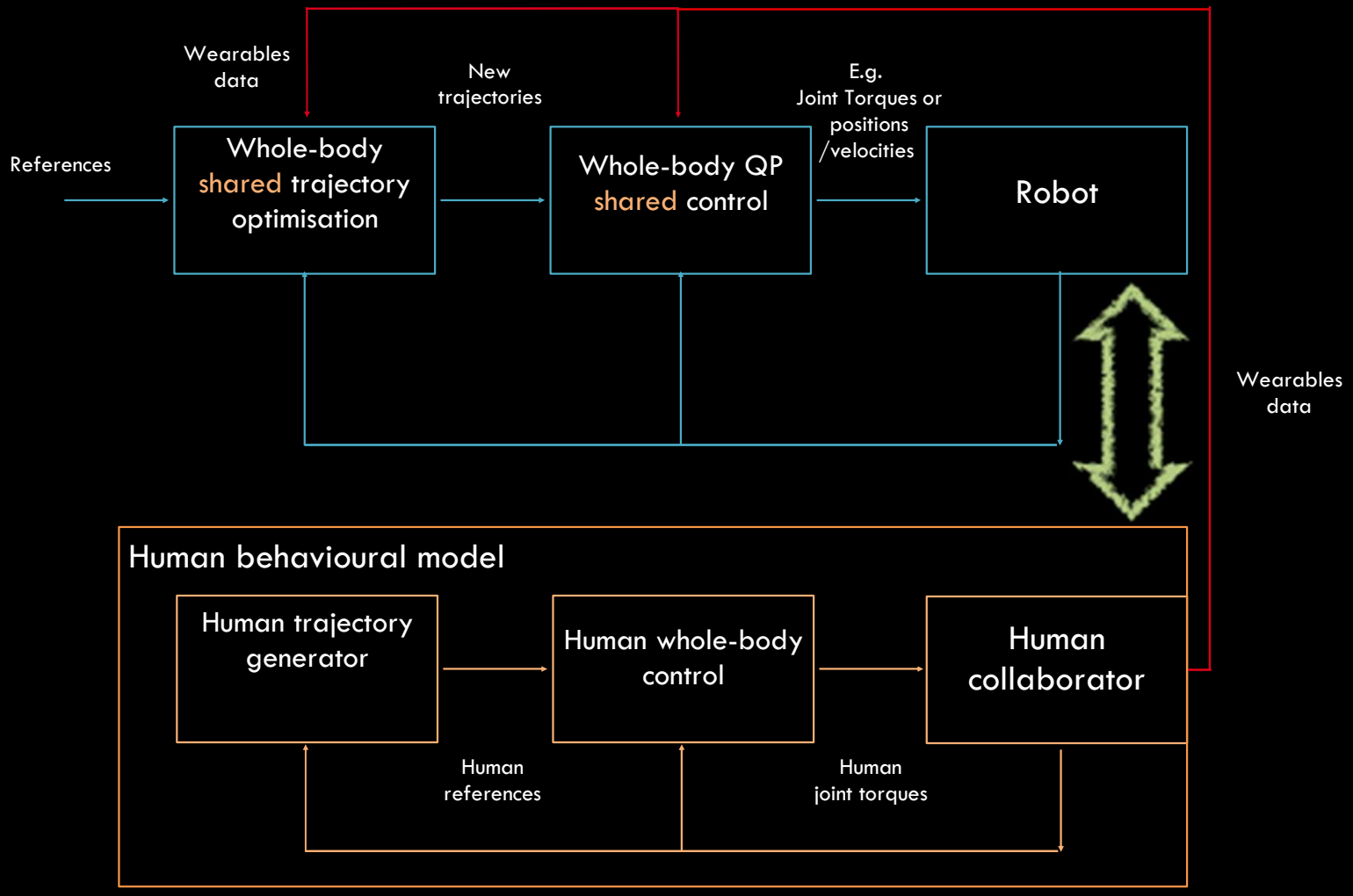
Dafarra et al. “iCub 3 Avatar System” Arxiv, 2022

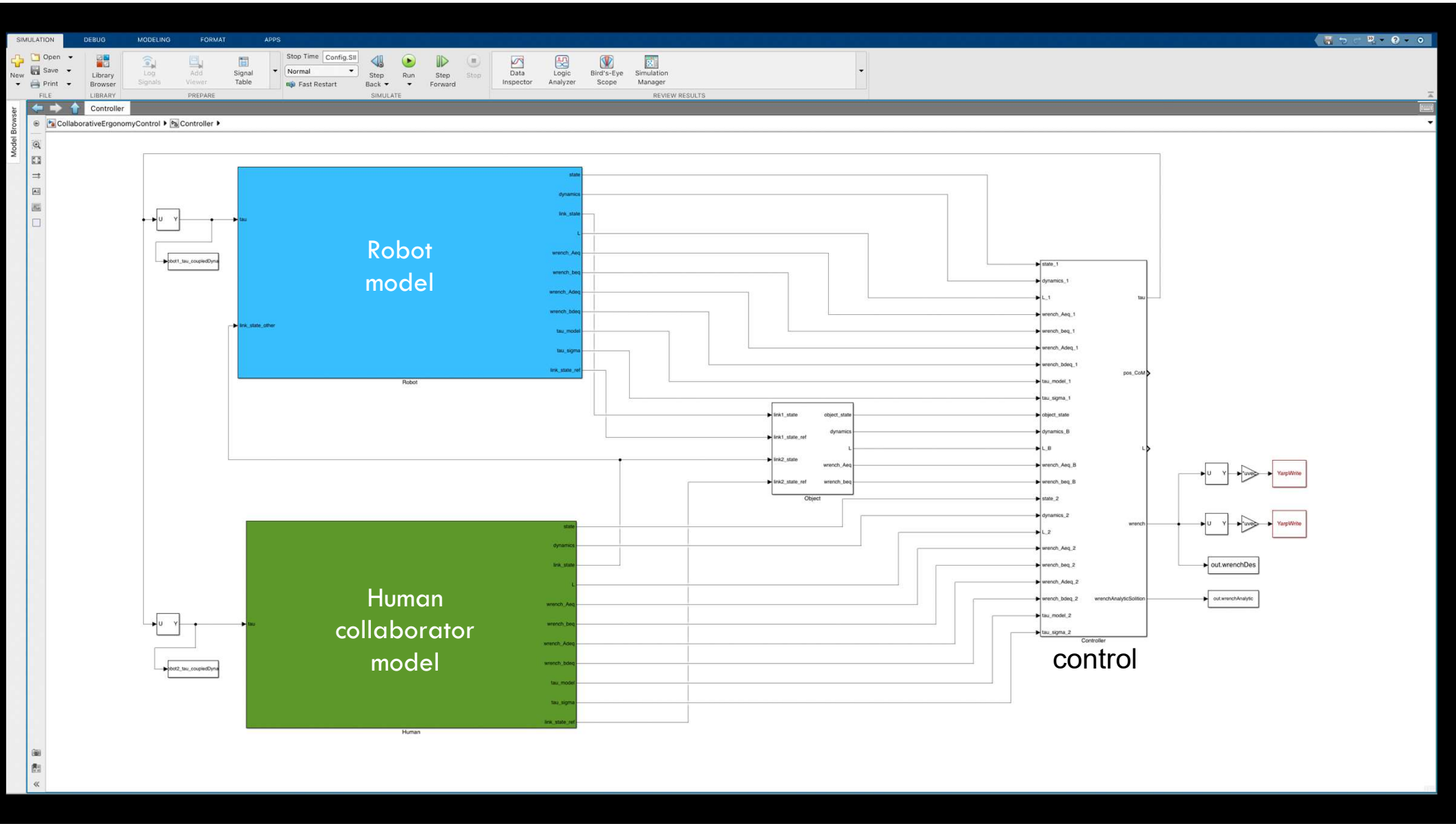

iit

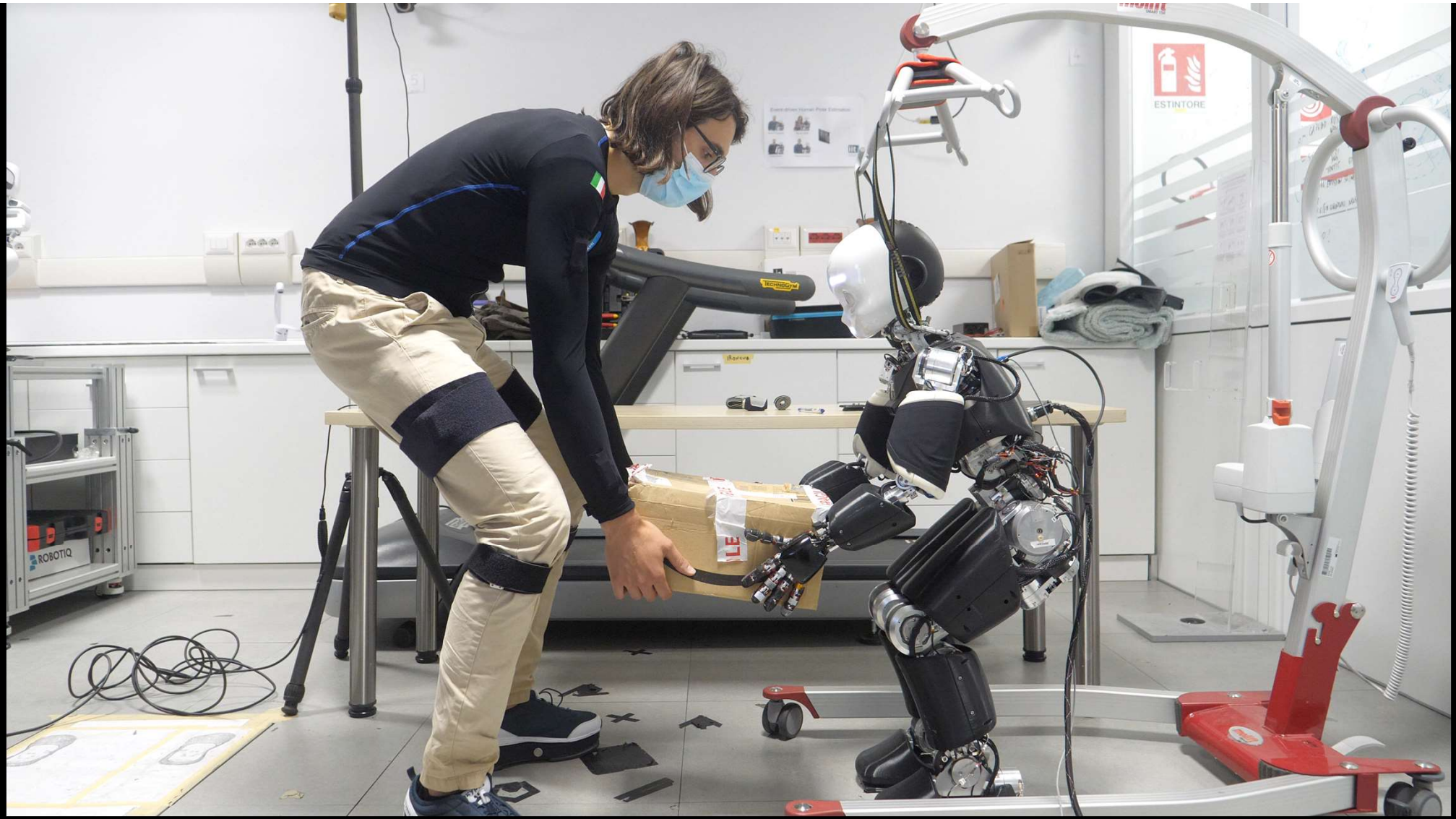
A unified control architecture for iCub during physical collaboration



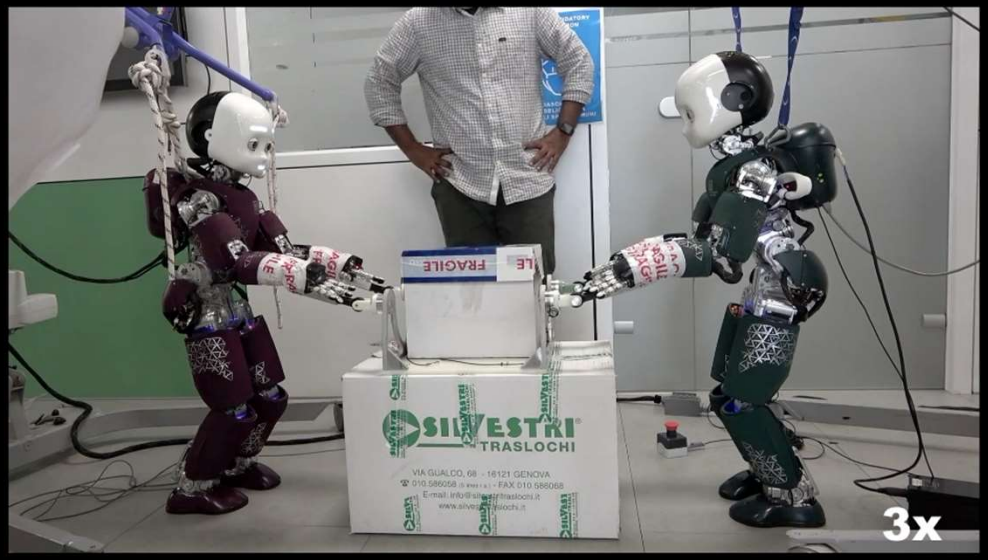
A unified control architecture for iCub during physical collaboration

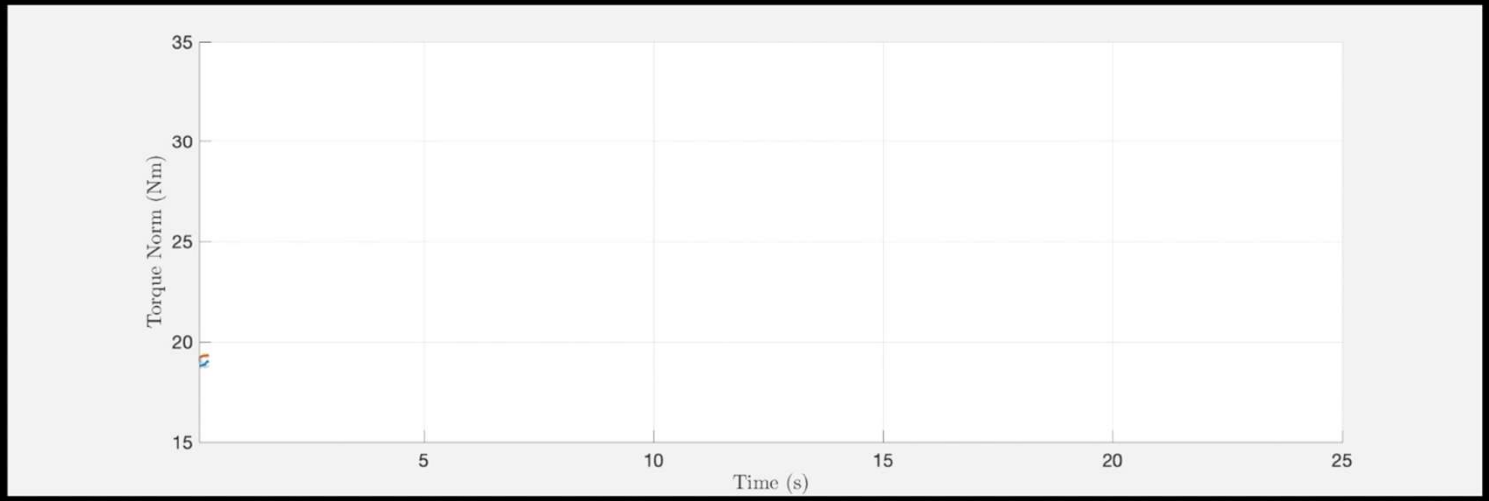



Robot model
Human collaborator model
control
Controller
CollaborativeErgonomyControl
Robot
Object
Human



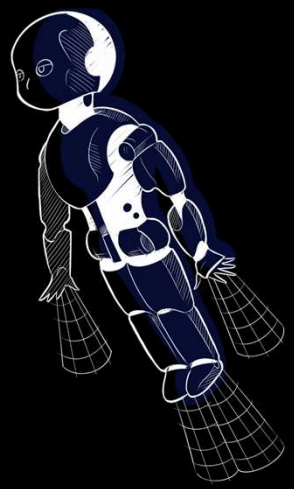
Rapetti et al. “A Control Approach for Human-Robot Ergonomic Payload Lifting ”, IEEE ICRA, 2023





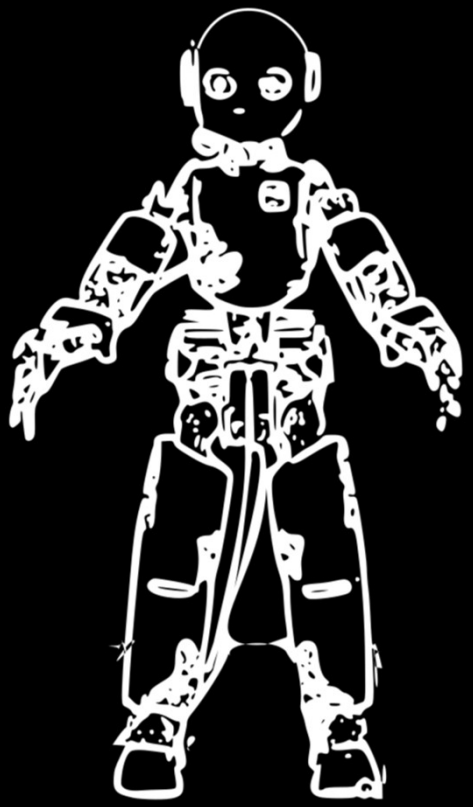
Rapetti et al. "Shared Control of Robot-Robot Collaborative Lifting with Agent Postural and Force Ergonomic Optimization", IEEE ICRA, 2021

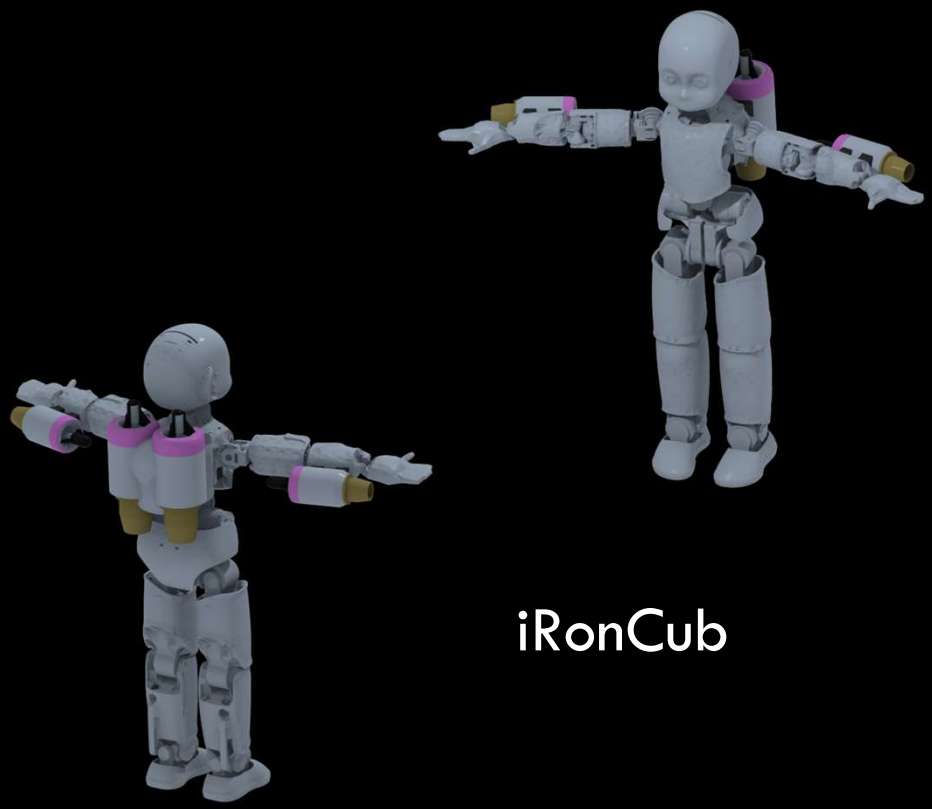
Evolving iCub for:



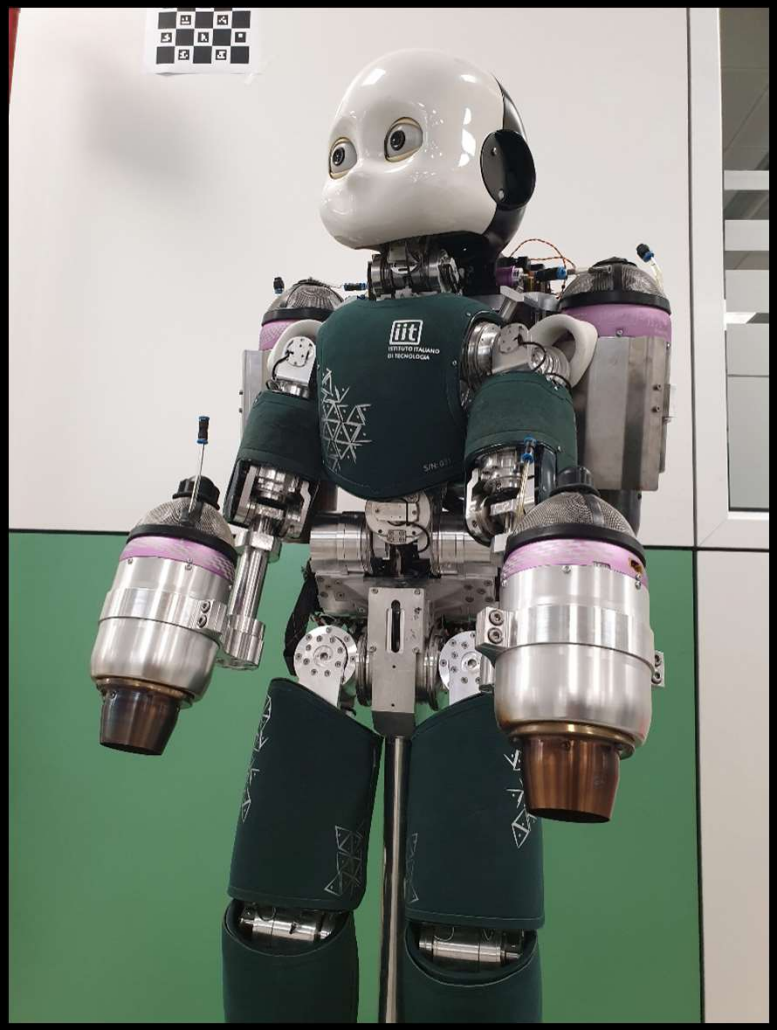
Aerial Humanoid Robotics

iRonCub

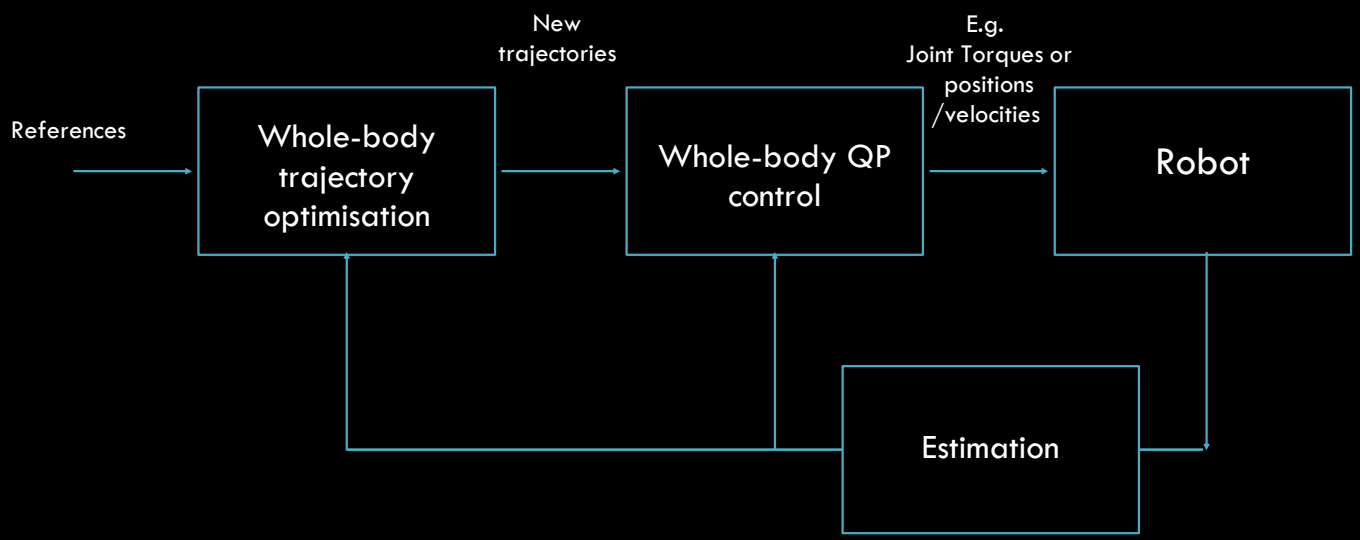




iRonCub



The control architecture for the iRonCub



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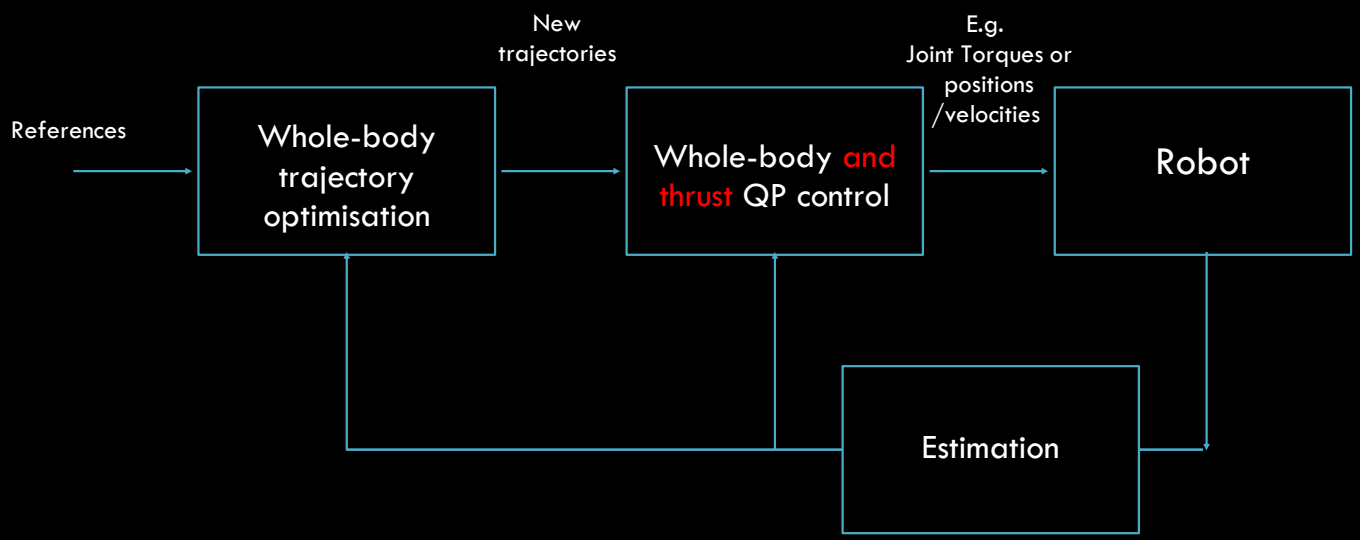
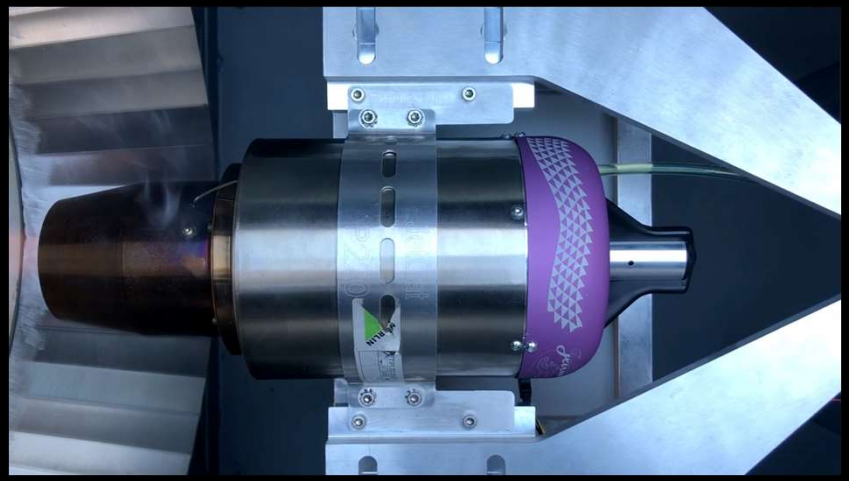


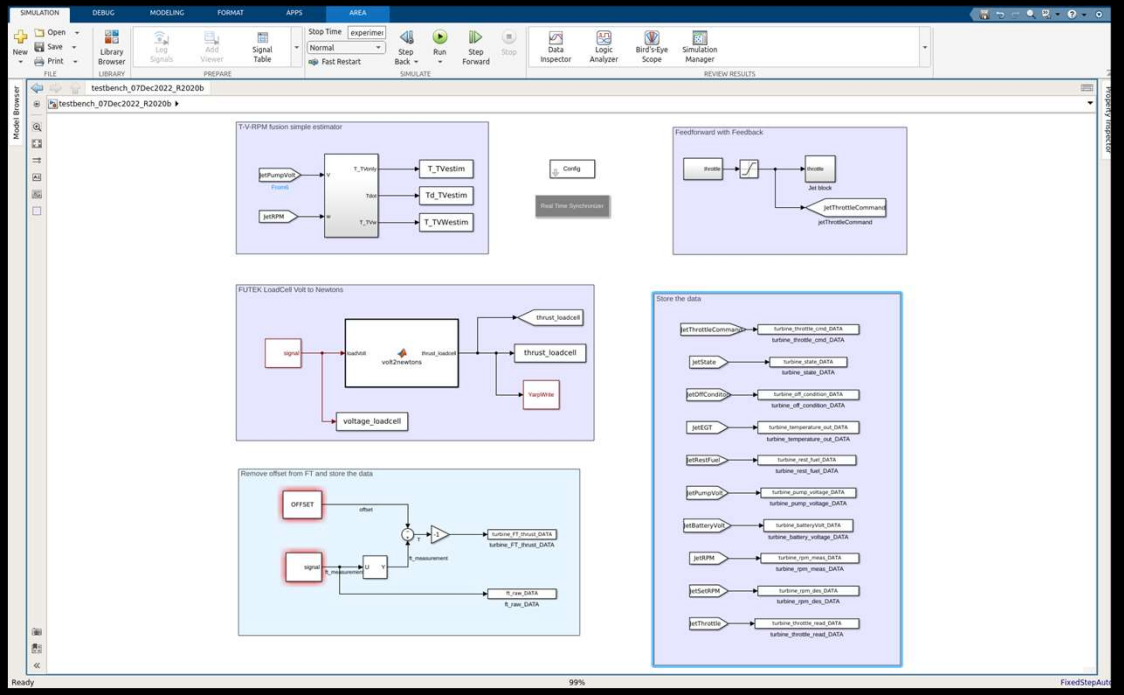
Turbine models?

Test-bench for jet engines system identification

Simulink model for:

- Thrust estimation
- Jet control
- Data collection for model identification





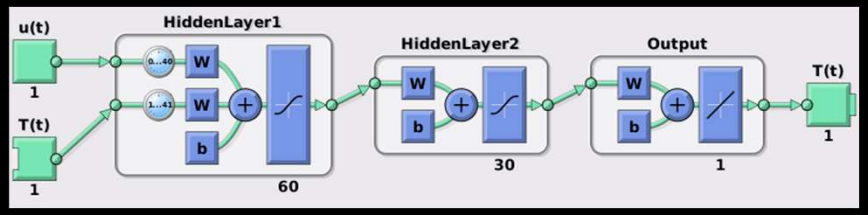
L'Erario et al. "Modeling, Identification and Control of Model Jet Engines for Jet Powered Robotics" IEEE RA-L, 2020

Momim et al. "Nonlinear Model Identification and Observer Design for Thrust Estimation of Small-scale Turbojet Engines" IEEE ICRA, 2022

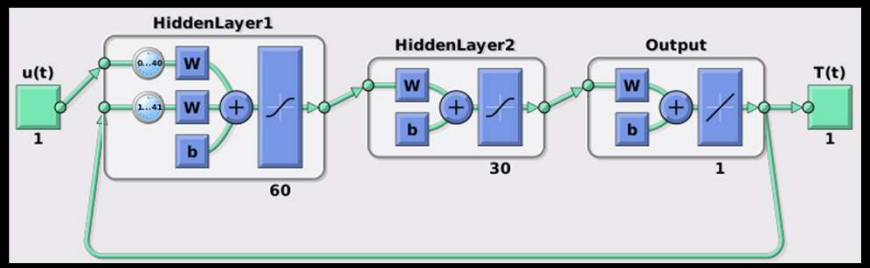
Digital twin for jet engines

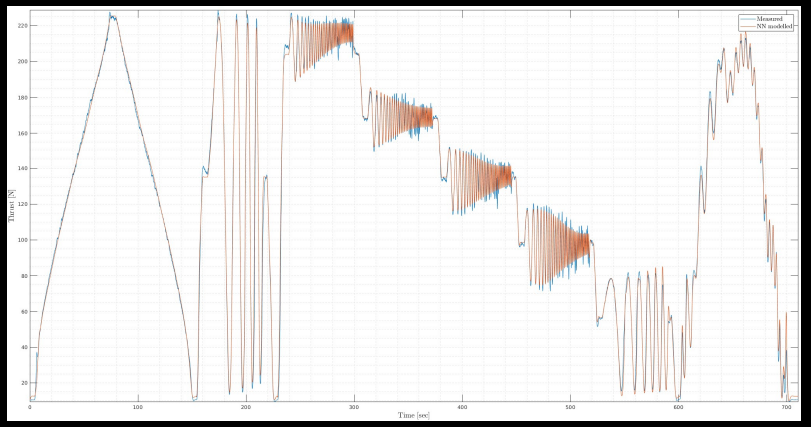
$$T_k = NN(u_k, u_{k-1}, \ldots, u_{k-p}, T_{k-1}, T_{k-2}, \ldots, T_{k-q}; \Theta)$$

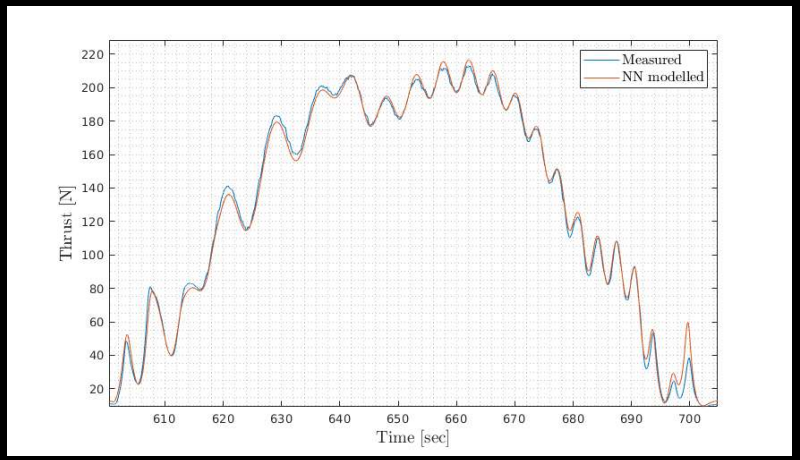
Training



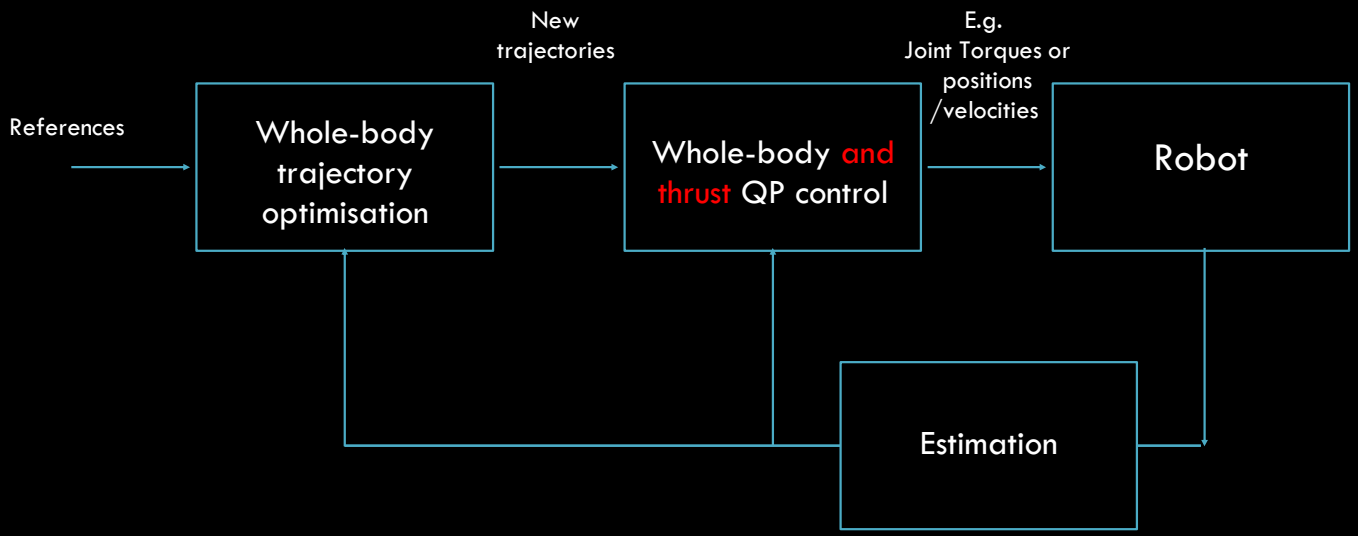
Testing

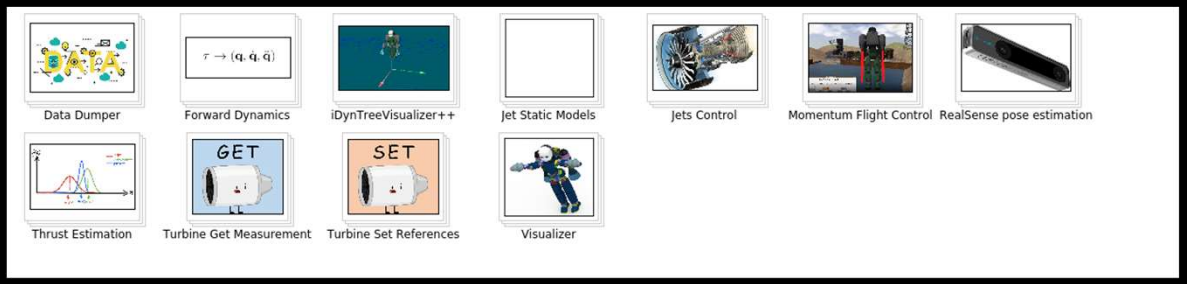




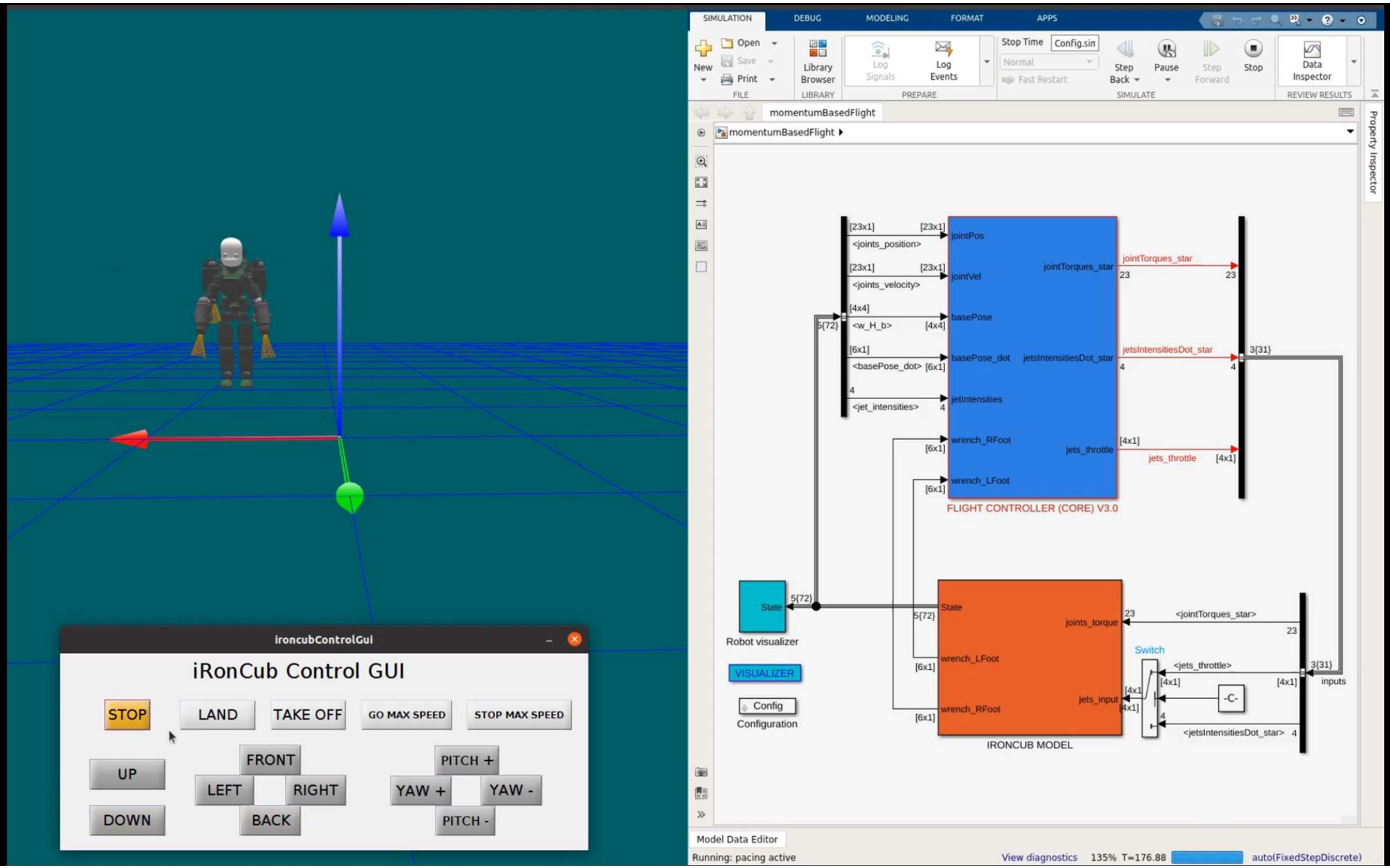


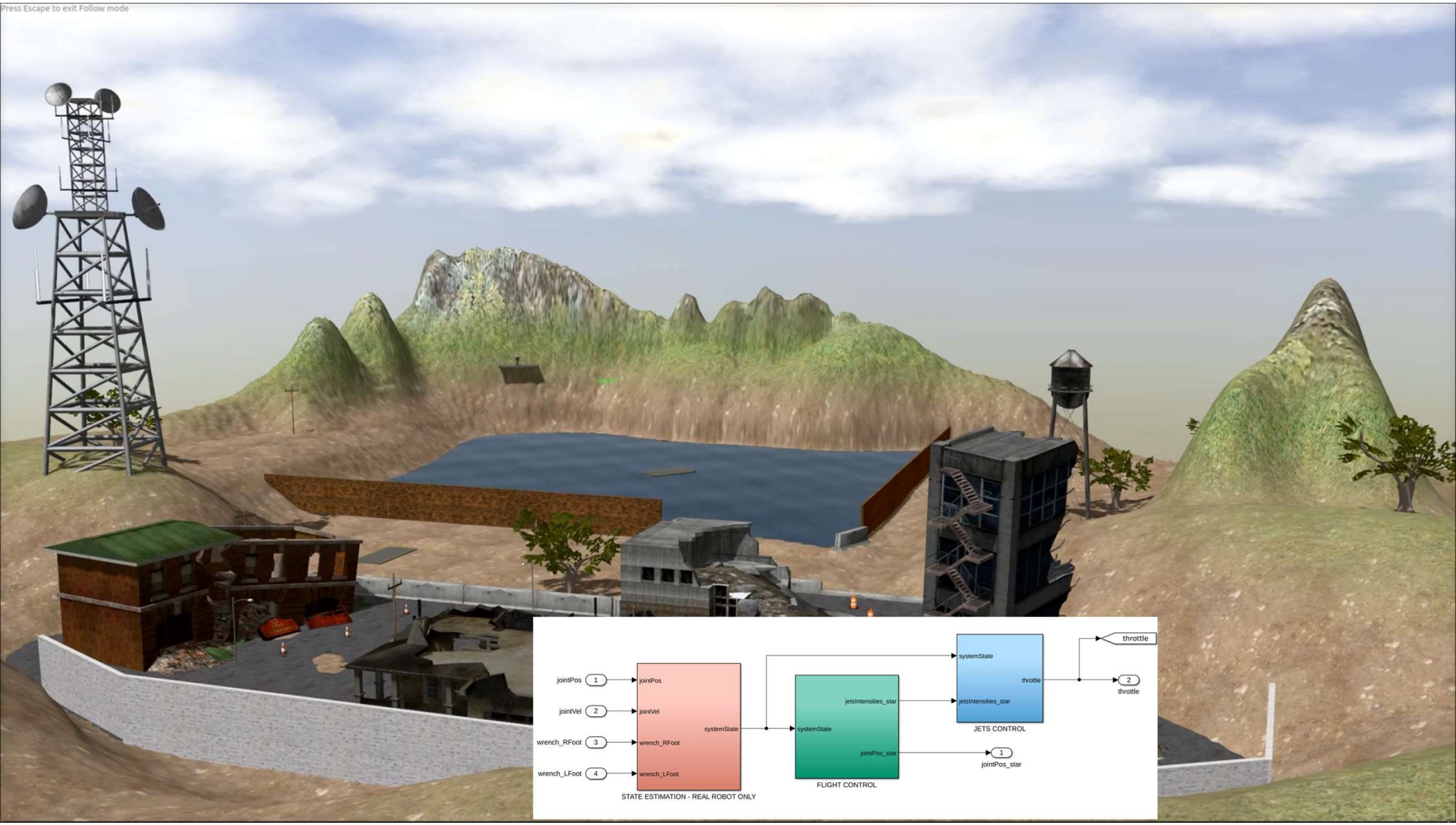
The control architecture for the iRonCub: Simulink library

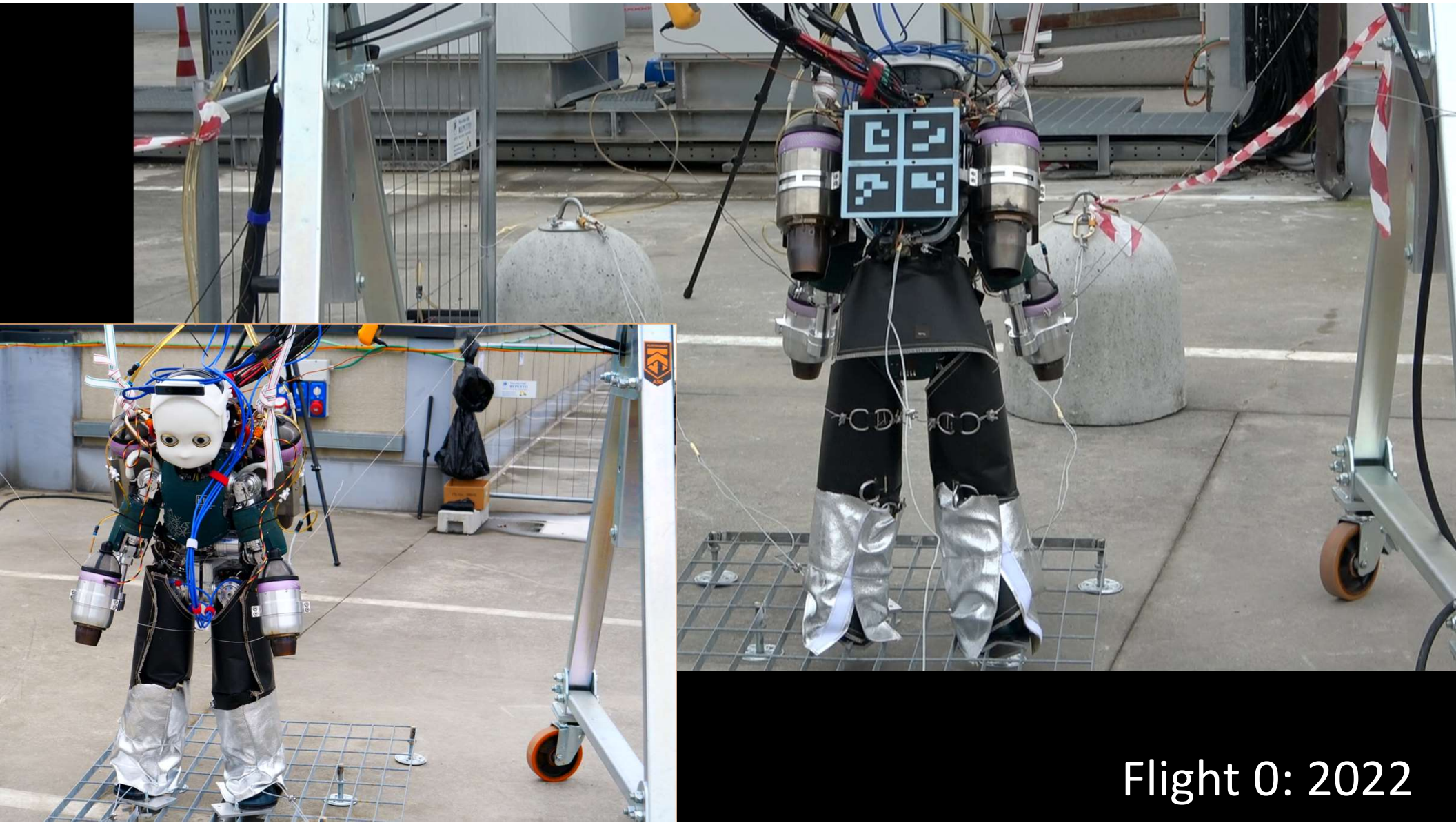




- Control System Toolbox
- Curve Fitting Toolbox
- Robotics System Toolbox
- Stateflow
- Symbolic Math Toolbox
- WBToolbox https://github.com/robotology/wb-toolbox
- https://github.com/ami-iit/ironcub_software


ironcubControlGui
iRonCub Control GUI
STOP
LAND
TAKE OFF
GO MAX SPEED
STOP MAX SPEED
UP
FRONT
LEFT
RIGHT
BACK
DOWN
PITCH +
YAW +
YAW -
PITCH -
SIMULATION
DEBUG
MODELING
FORMAT
APPS
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Log Signals
Log Events
PREPARE
Stop Time
Config.sin
Normal
Fast Restart
Step Back
Pause
Step Forward
Stop
SIMULATE
Data Inspector
REVIEW RESULTS
momentumBasedFlight
Property Inspector
[23x1]
<joints_position>
<joints_velocity>
[4x4]
<w_H_b>
[6x1]
<basePose_dot>
4
<jet_intensities>
jointPos
jointVel
basePose
basePose_dot
jetIntensities
wrench_RFoot
wrench_LFoot
jointTorques_star
jetsIntensitiesDot_star
jets_throttle
FLIGHT CONTROLLER (CORE) V3.0
3(31)
State
5(72)
Robot visualizer
VISUALIZER
Config
Configuration
joints_torque
<jointTorques_star>
Switch
<jets_throttle>
jets_input
-C-
<jetsIntensitiesDot_star>
inputs
IRONCUB MODEL
Model Data Editor
Running: pacing active
View diagnostics
135% T=176.88
auto(FixedStepDiscrete)


Press Escape to exit Follow mode
jointPos
1
jointVel
2
wrench_RFoot
3
wrench_LFoot
4
jointPos
jointVel
wrench_RFoot
wrench_LFoot
systemState
STATE ESTIMATION - REAL ROBOT ONLY
systemState
jetsIntensities_star
jointPos_star
FLIGHT CONTROL
systemState
jetsIntensities_star
throttle
JETS CONTROL
throttle
2
throttle
1
jointPos_star

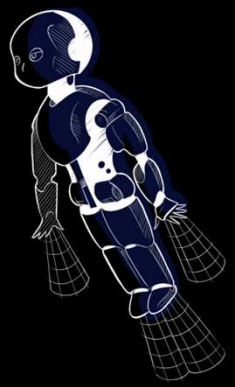

Flight 0: 2022

Flight 1: soon.

Why and When MathWorks Tools?

1. Lower barriers for non-expert coders

2. Fast analysis, rapid prototyping and deployment



Aerial Humanoid Robotics

Human-Robot Collaboration

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github.com/ami-iit

"The trouble with our times is that the future is not what it used to be."

Paul Valéry

INAIL
ISTITUTO NAZIONALE PER L'ASSICURAZIONE CONTRO GLI INFORTUNI SUL LAVORO

CAMOZZI

DANIELI AUTOMATION

CLASSIFIED

HONDA