ISTITUTO ITALIANO
DI TECNOLOGIA
DYNAMIC INTERACTION CONTROL

Aerial Humanoid Robotics

25 November 2020

Shanghai Lectures

Daniele Pucci


DYNAMIC INTERACTION CONTROL
LAB WORKSHOP 2020
CAMOZZI
HRI

JOINT LABS with INDUSTRIES

EU PROJECTS

DANIELI

CAMOZZI

HRI

Honda Research Institute JP

CLASSIFIED

iit

An.Dy

SOFTMANBOT

Agent-robot collaboration (ARC)

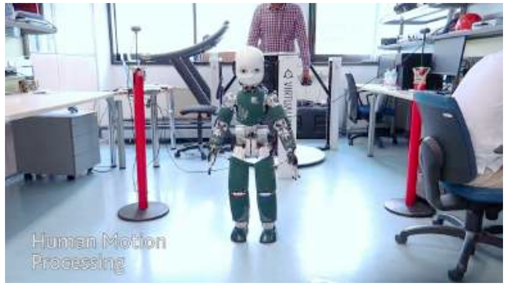
Cobots, wearable sensors, and ergonomy

Aerial Humanoid Robotics (AHR)

Disaster response, heavy-payload delivery

Telexistence (TELX)

Telepresence, and virtual reality



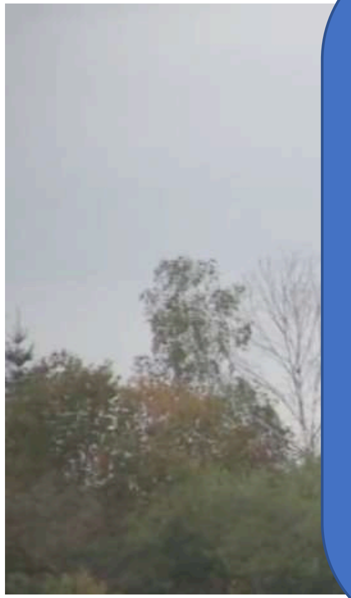
Why

Manipulation

Terrestrial Locomotion

Aerial Locomotion

Manipulation

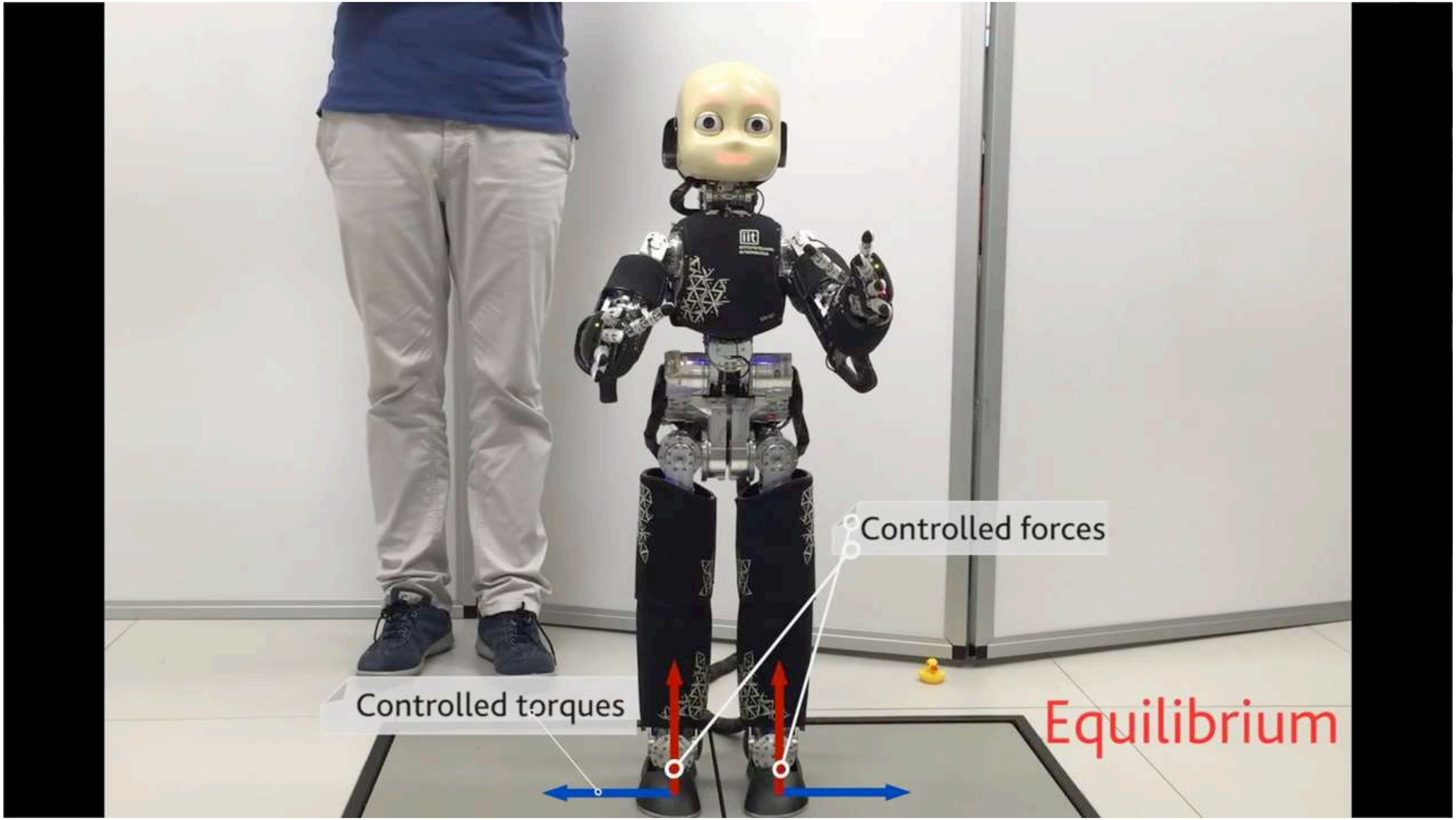


Aerial Humanoid Robotics

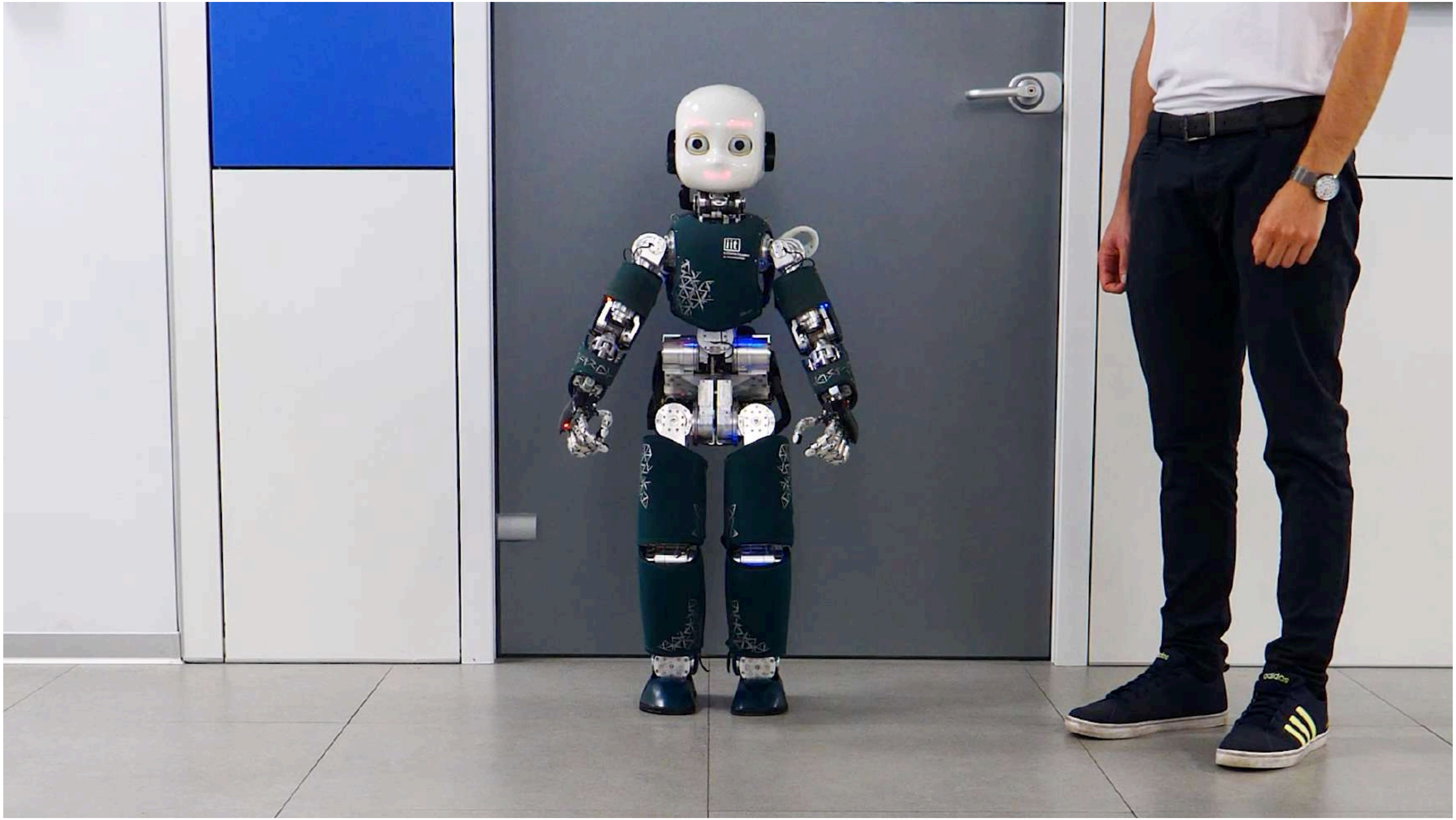
Aerial Locomotion

Terrestrial Locomotion

What

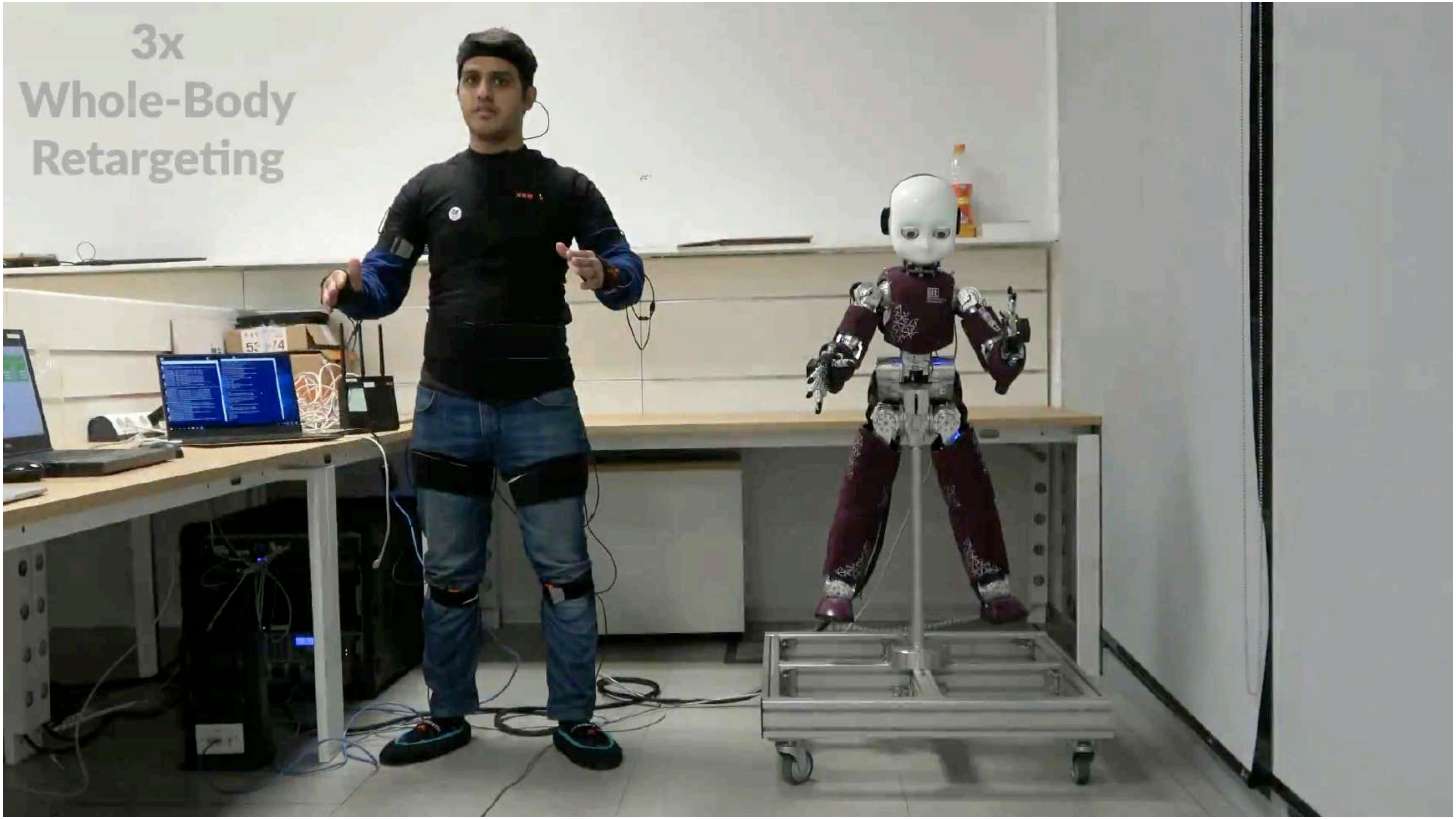


Nava et al. “Stability Analysis and Design of Momentum-based Controllers for Humanoid Robots” IEEE International Conference on Intelligent Robots and Systems (IROS) 2016
Pucci et al. "Highly dynamic balancing via force control,"IEEE-RAS International Conference on Humanoid Robots (Humanoids),” IEEE Humanoids, 2016



Romualdi et al. "A Benchmarking of DCM Based Architectures for Position, Velocity and Torque Controlled Humanoid Robots" IJHR, 2020

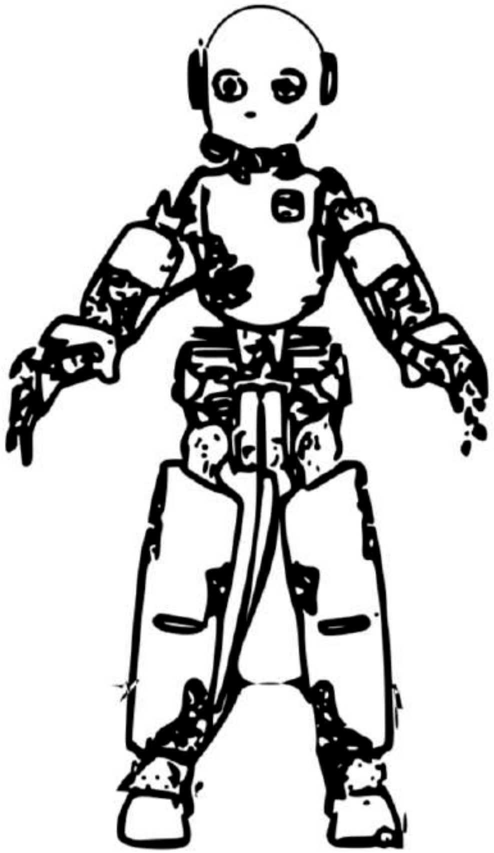
Shafiee et al. ",Online DCM Trajectory Generation for Push Recovery of Torque-Controlled Humanoid Robots" IEEE HUMANOIDS, 2020



Elobaid et al. "Telexistence and Teleoperation for Walking Humanoid Robots" Advances in Intelligent Systems and Computing, Springer Nature Switzerland AG, 2020
Darvish et al. "Whole-Body Geometric Retargeting for Humanoid Robots" IEEE-RAS International Conference on Humanoid Robots (HUMANOIDS), 2019

How do we make it fly?

How do we make iCub fly? iRonCub



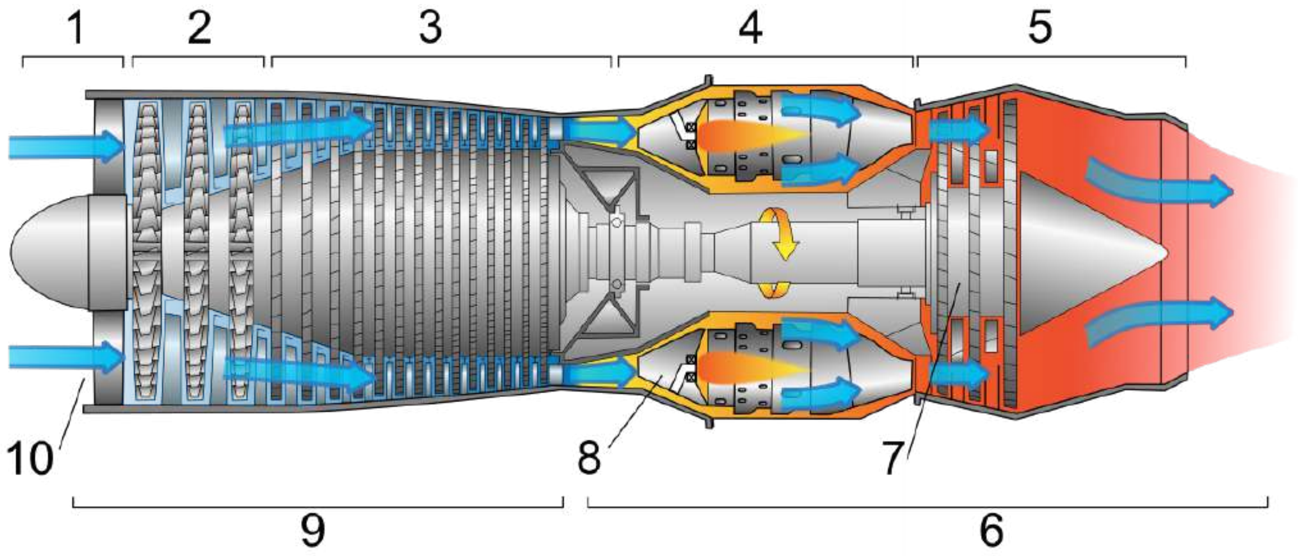
How do we make a humanoid robot fly?

Jet Identification & Jet Control

Mechanics & Electronics

Body Control & Experiments

Jet Identification & Jet control



JetCat

JETCAT ENGINES

The P100-RX and the P220-RXi are two model jet engines developed by JetCat.

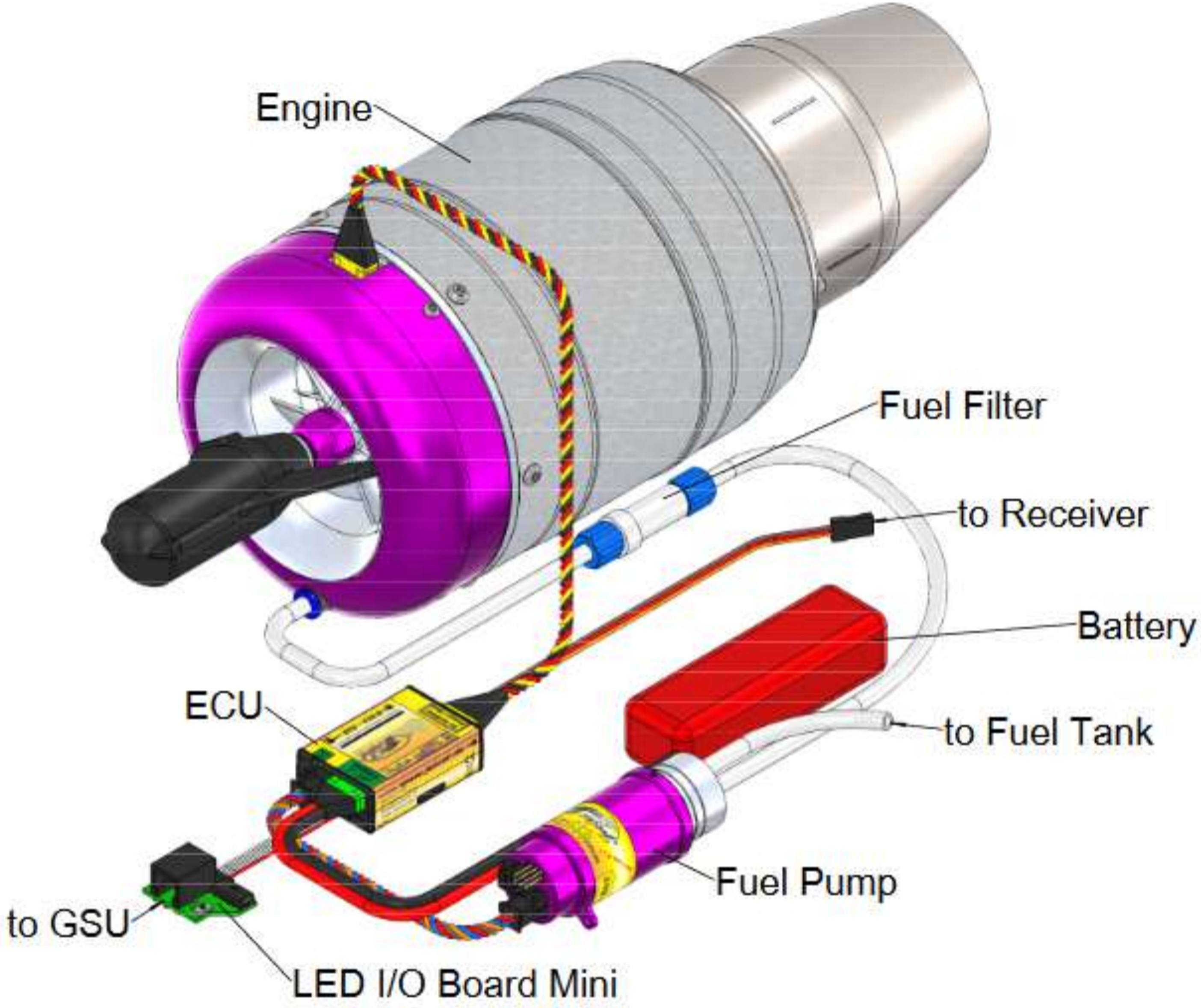
Jet engine model	P100-RX	P220-RXi
Exhaust gas temperature	480-720 °C	480-750 °C
Nominal Max. Thrust	100 N	220 N
Weight	1080 g	1850 g
Length	241 mm	307 mm
Diameter	97 mm	116.8 mm
Max rpm (1/min)	154000 1/min	117000 1/min

MODEL JET ENGINE

Throttle

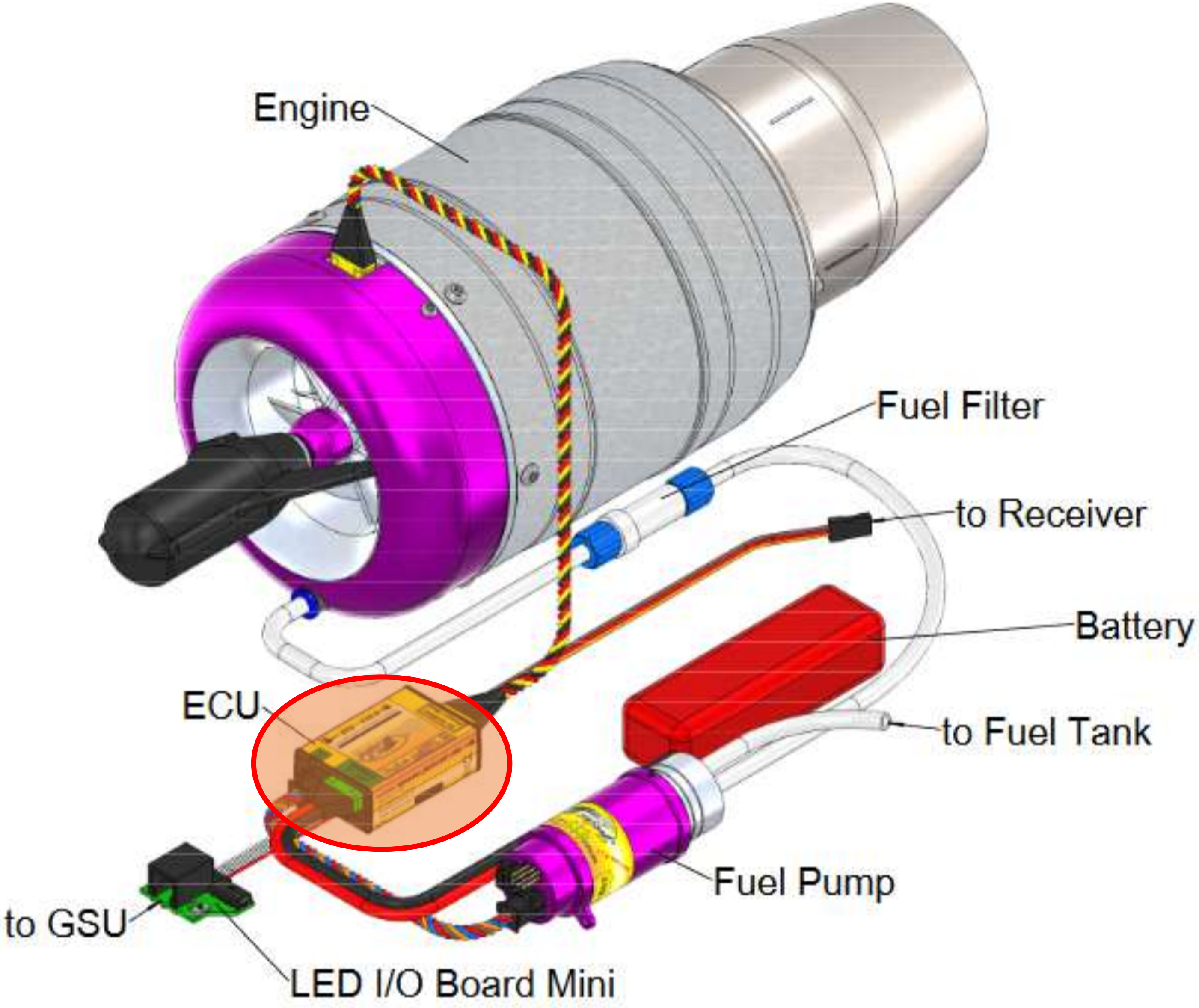
Thrust

HARDWARE



Engine
Fuel Filter
to Receiver
Battery
ECU
to Fuel Tank
Fuel Pump
to GSU
LED I/O Board Mini

HARDWARE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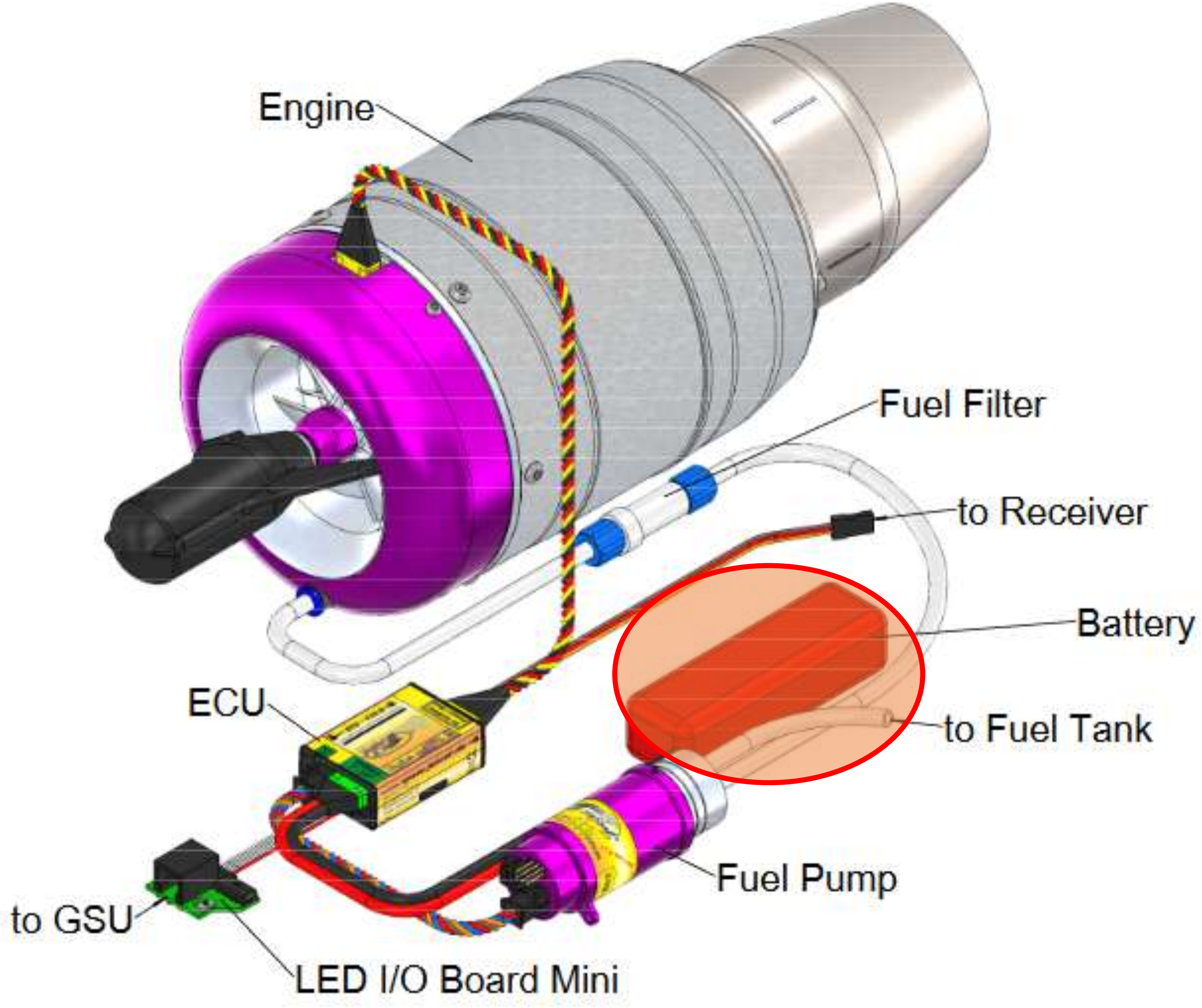

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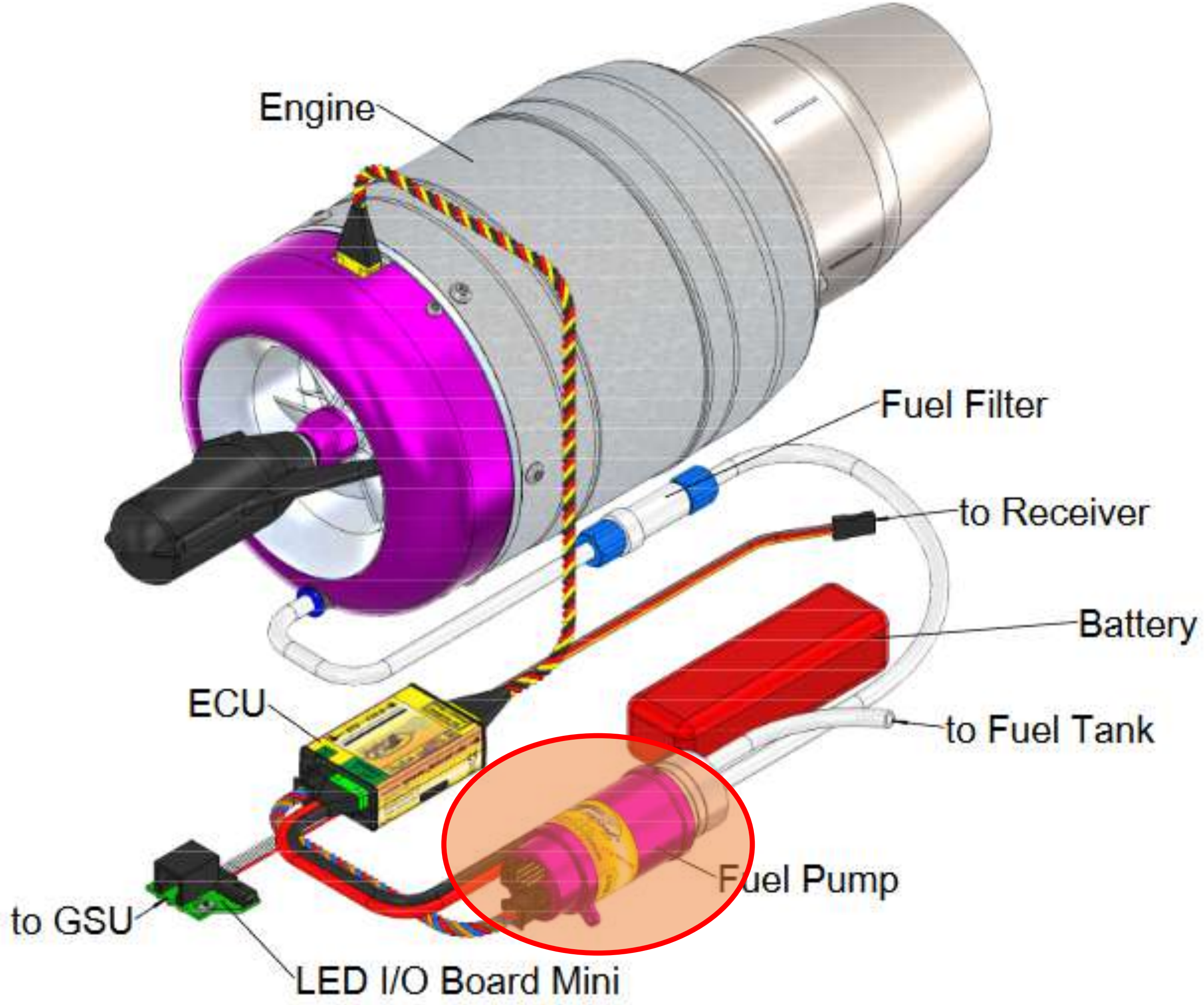

Engine
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to Receiver
Battery
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to Fuel Tank
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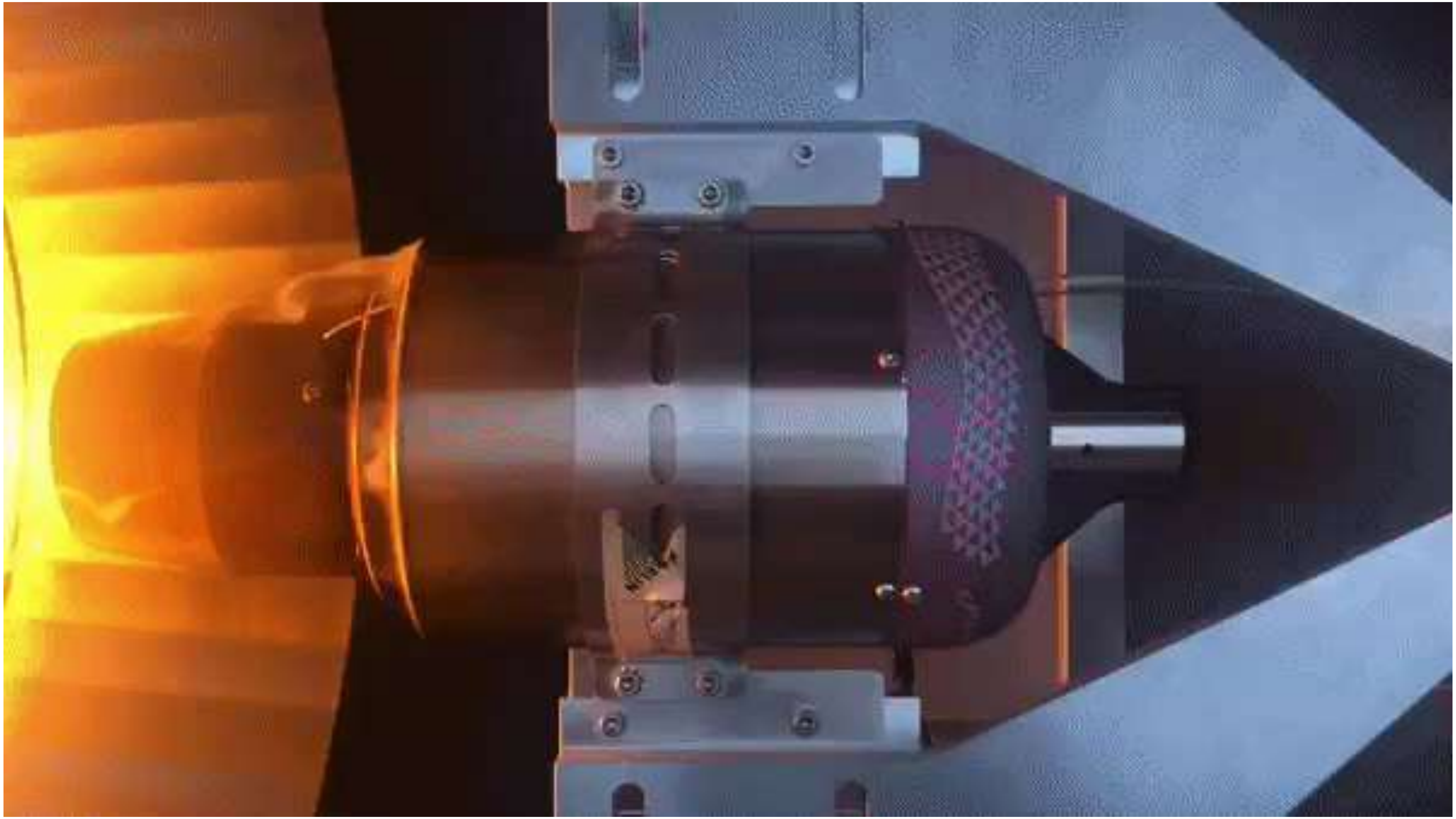
COMPUTER CONTROL

It can explode



THE TEST BENCH

FOR EXPERIMENTAL ACTIVITIES

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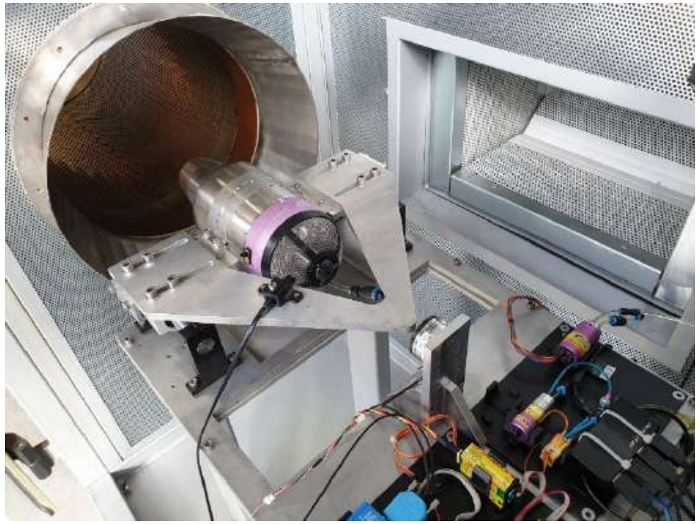
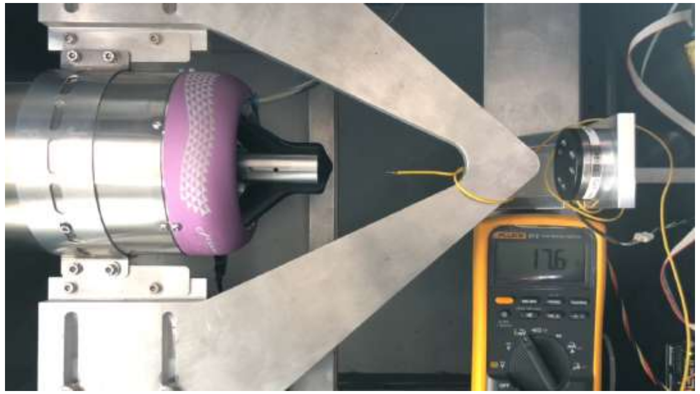
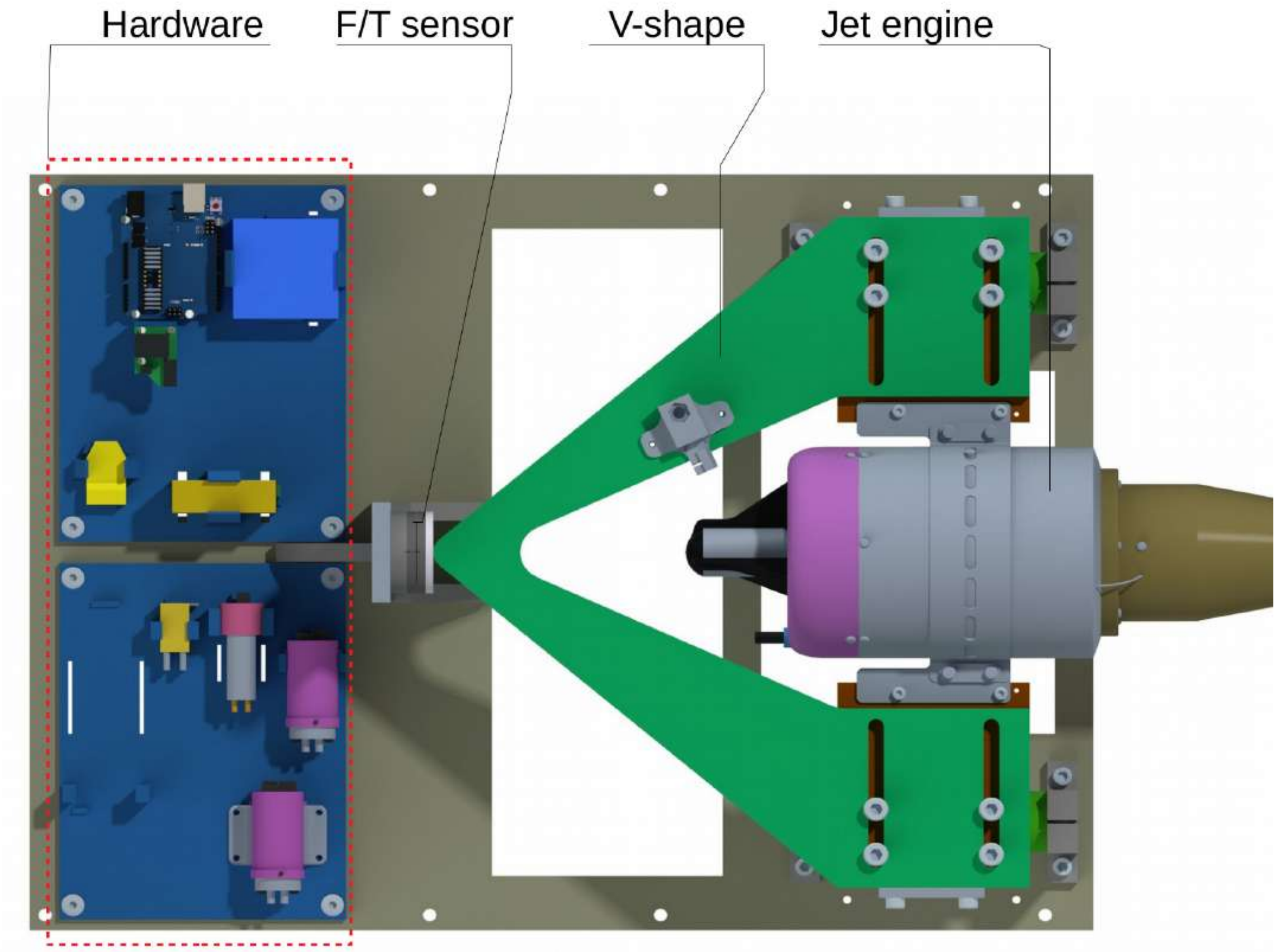
FOR EXPERIMENTAL ACTIVITIES







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

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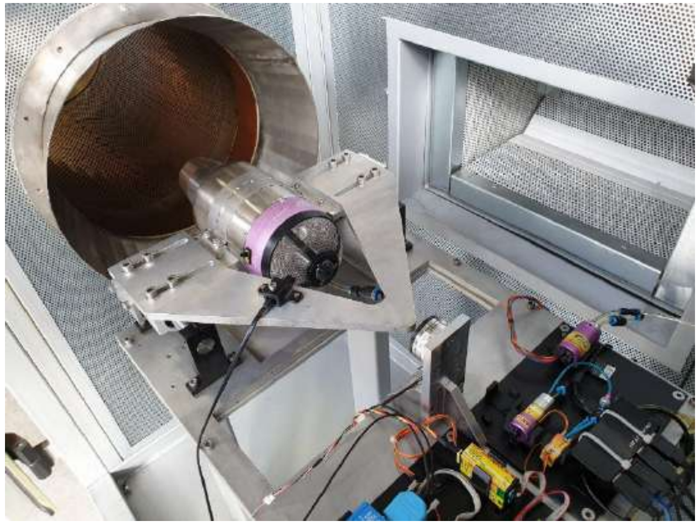

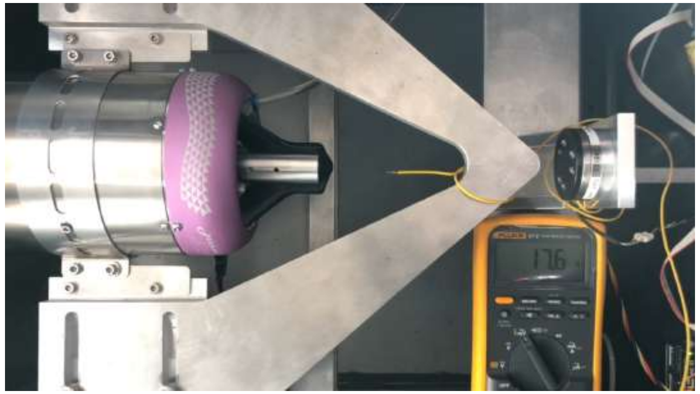

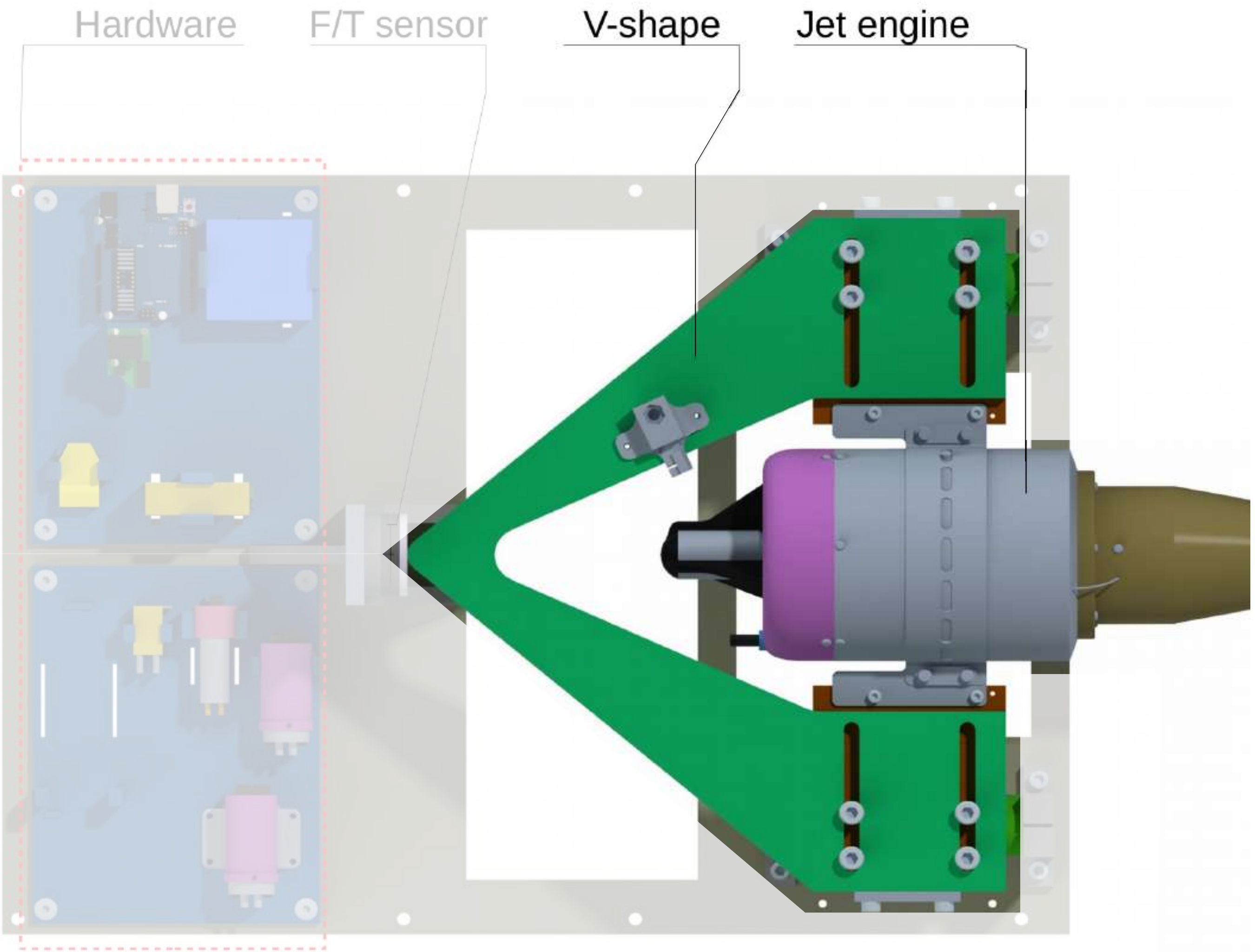

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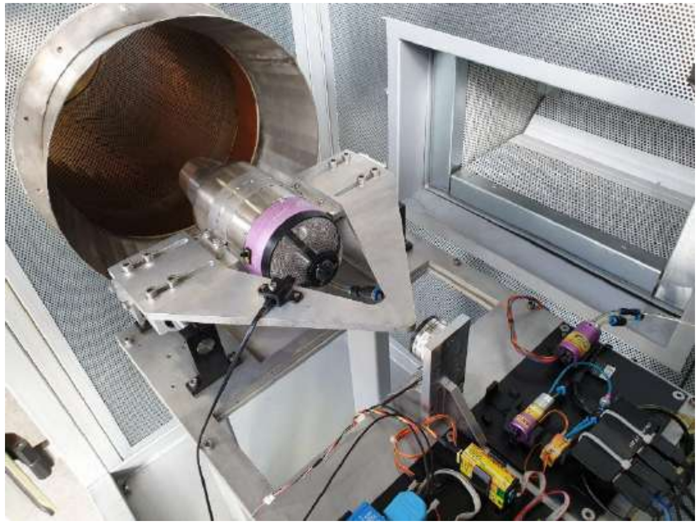

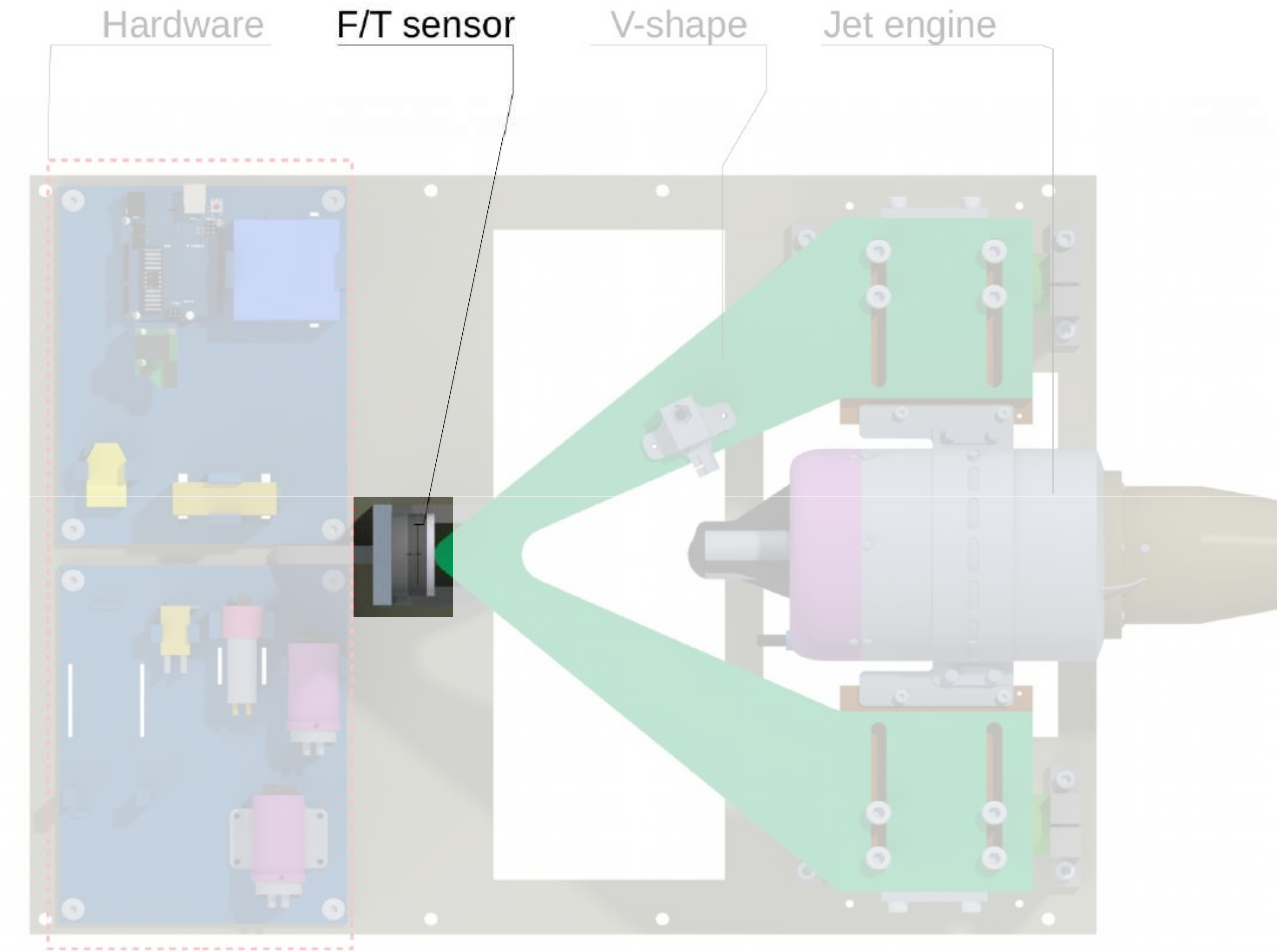

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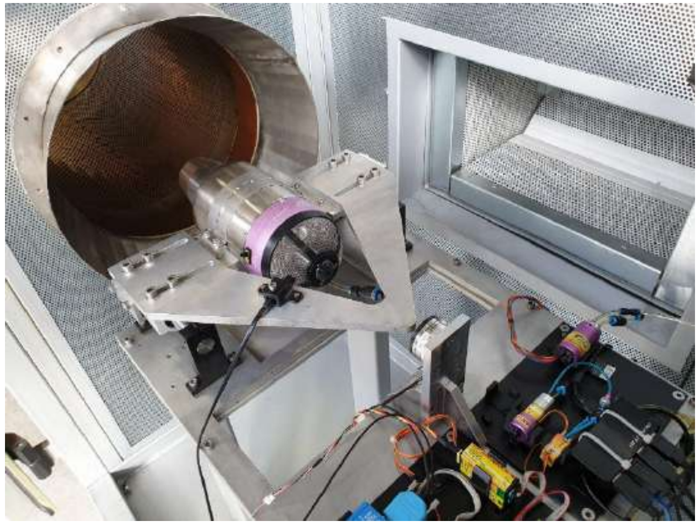
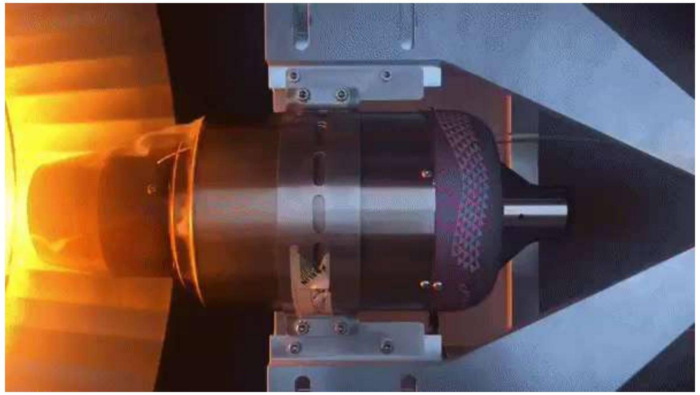
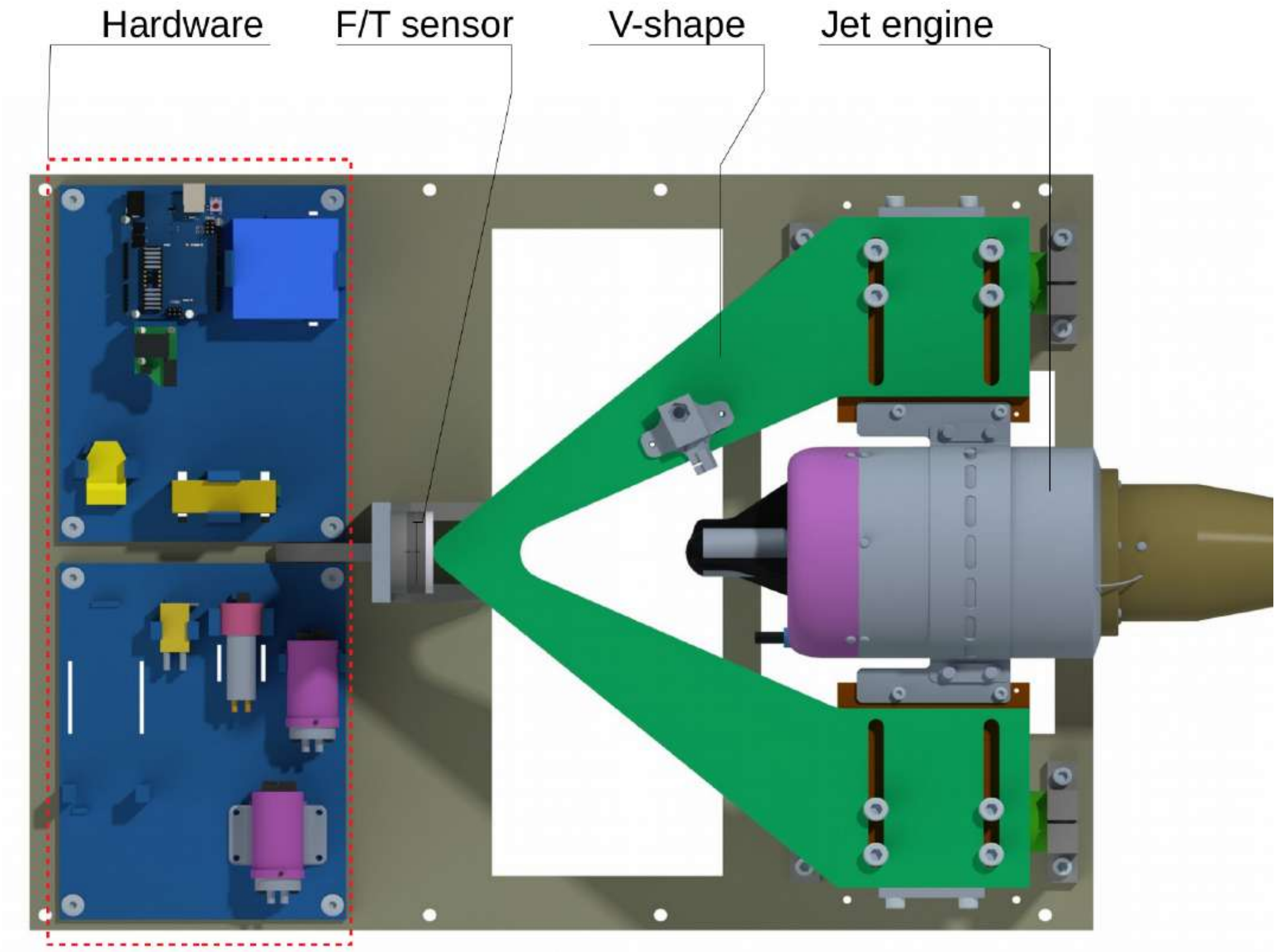






L'Erario et al. "Modeling, Identification and Control of Model Jet Engines for Jet Powered Robotics", IEEE RA-L 2020

THE GOAL

Discover model

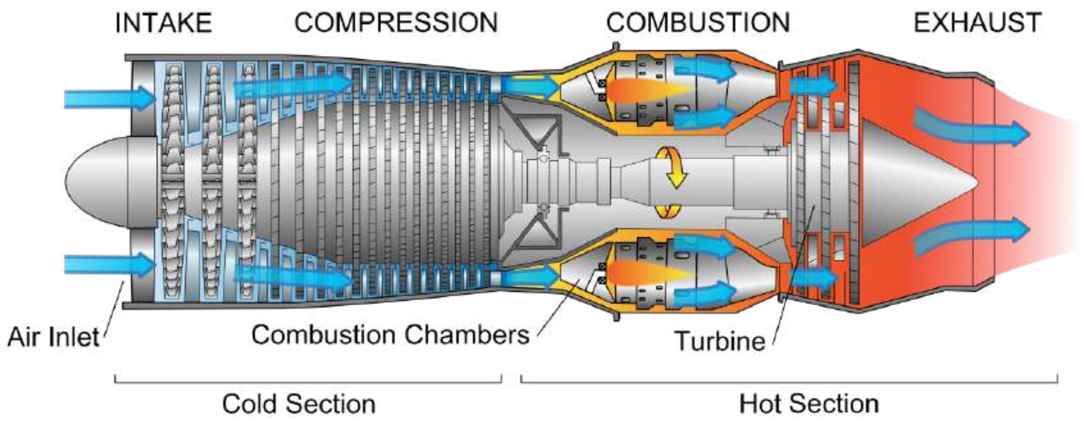
↓

Design control laws

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

JET THRUST

The thrust is generated by the variation of the momentum of the air.



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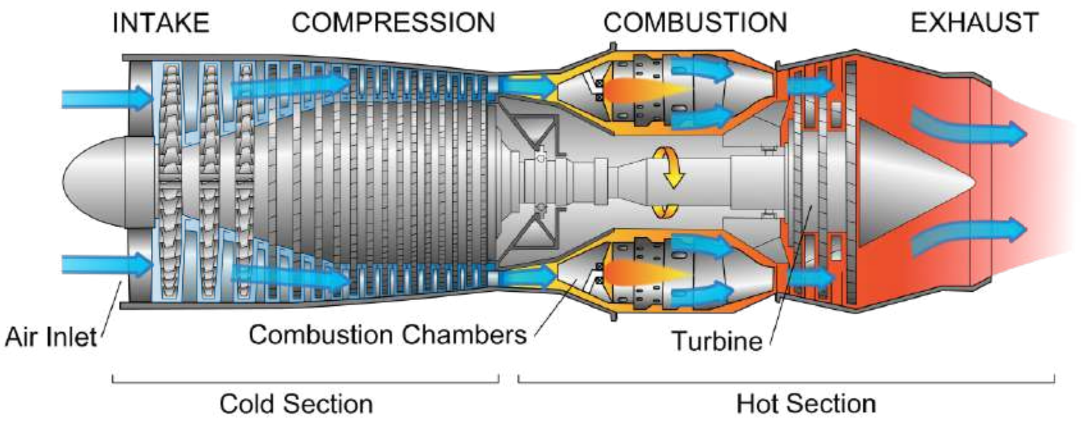


The thrust depends on:

- air pressure
- temperature
- propulsive system efficiency
- fuel type
- …

We usually do not have this information!

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

DATA DRIVEN METHODOLOGY

FOR GRAY BOX IDENTIFICATION

DATA ACQUISITION

↓

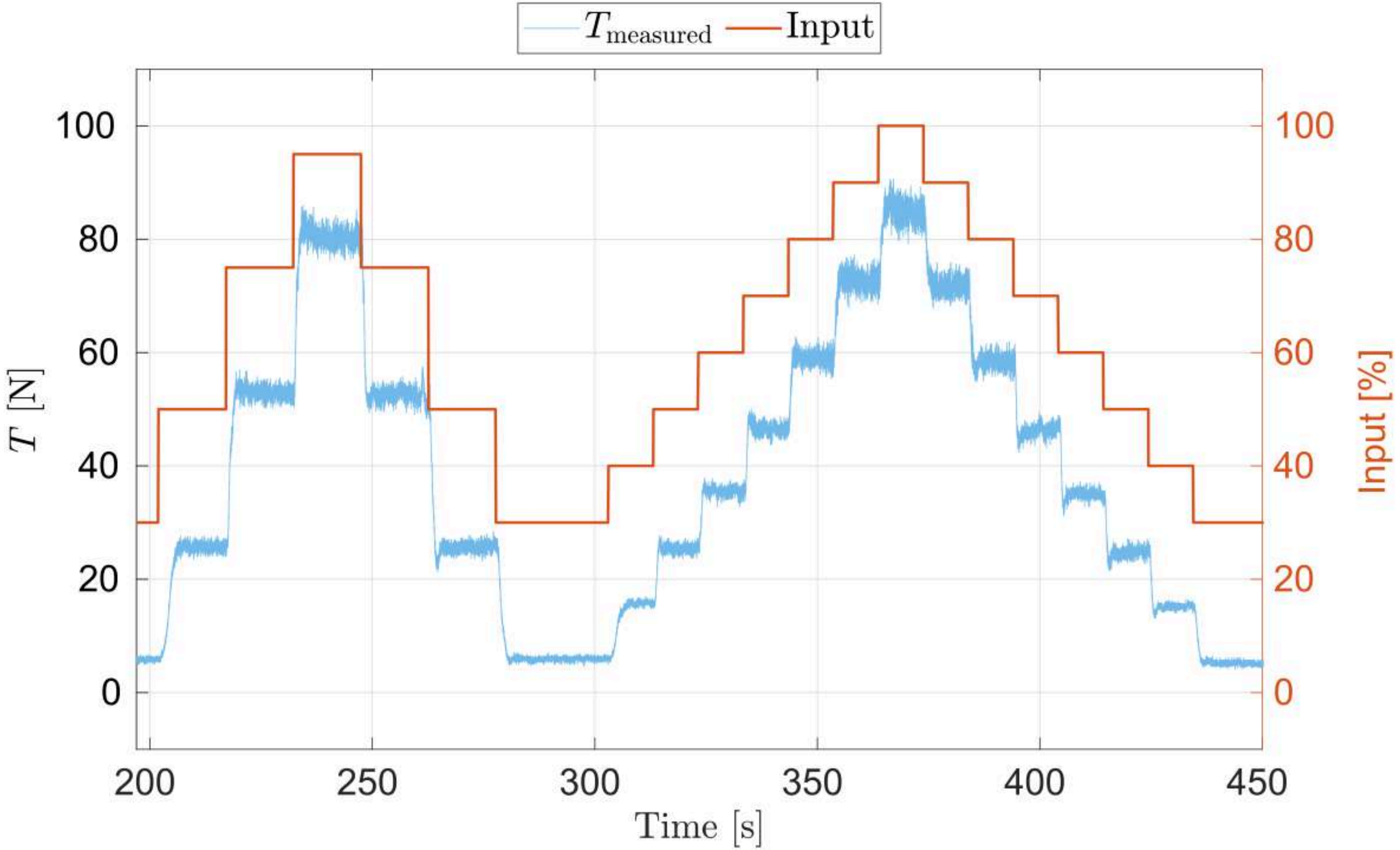
MODEL SELECTION

↓

PARAMETER ESTIMATION

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

DATASET



T_{measured}
Input
100
80
60
40
20
0
T [N]
Input [%]
200
250
300
350
400
450
Time [s]

MODEL SELECTION

SPARSE IDENTIFICATION OF NONLINEAR DYNAMICS

- data driven approach
- based on **sparse regression**
- features selection of arbitrary combination of state and input
- $\dot{T}$ and $\ddot{T}$ estimated with non causal filters

SPARSE REGRESSION OUTPUT:

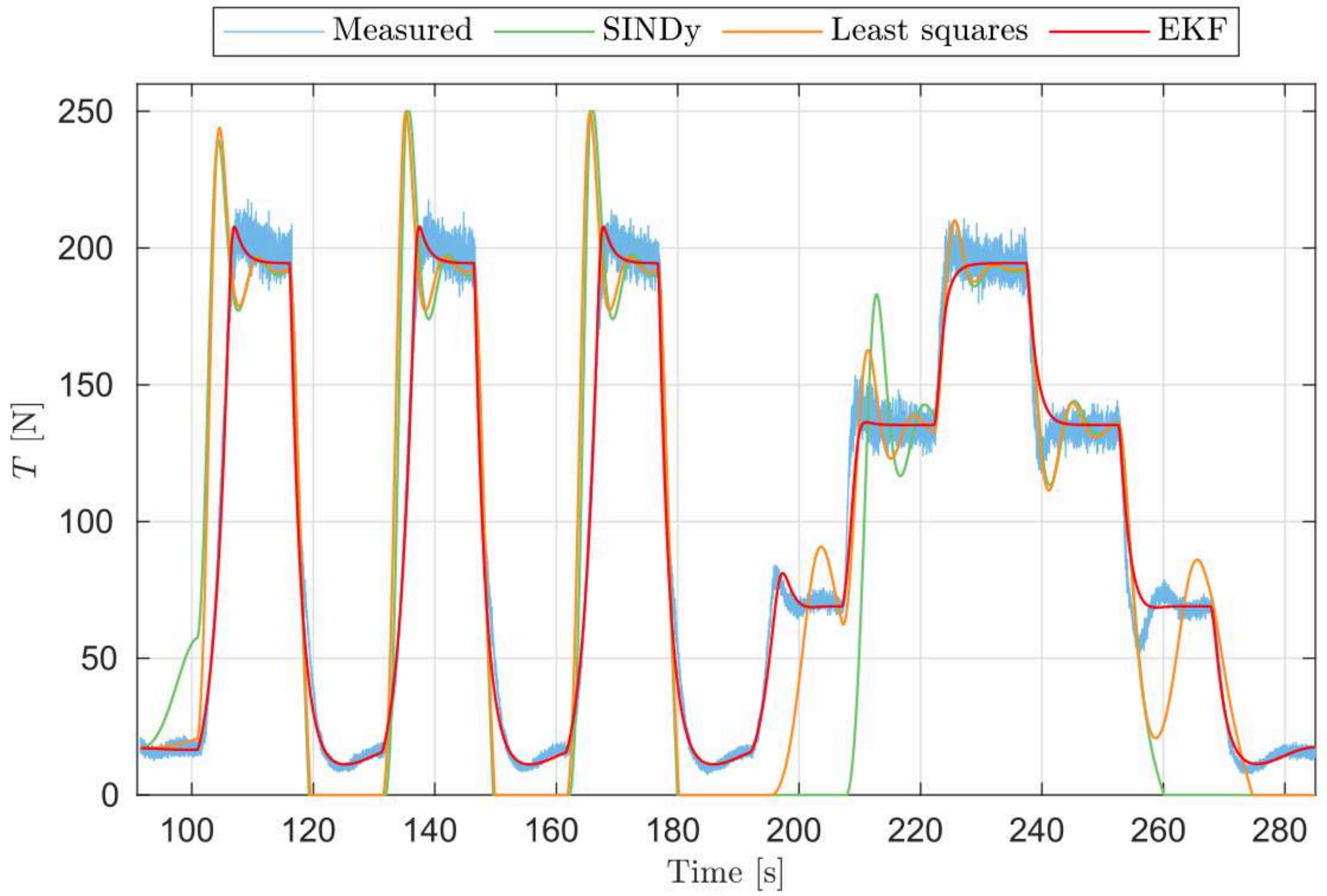
$$\ddot{T} = a_1 + a_2 T + a_2 T^2 + a_3 \dot{T} + a_4 T\dot{T} + a_5 \dot{T}^2 + a_6 u + a_7 T u + a_8 \dot{T} u + a_9 u^2$$

S. L. Brunton, J. L. Proctor, and J. N. Kutz, "Discovering governing equations from data by sparse identification of nonlinear dynamical systems," Proceedings of the National Academy of Sciences, vol. 113, no. 15, pp. 3932–3937, 2016.

IDENTIFICATION RESULTS

VALIDATION DATASET

P220-RXi



	Mean absolute error [N]		
Jet model	EKF	LS	SINDy
P100-RX	**3.94**	4.40	5.11
P220-RXi	**6.77**	13.41	21.34

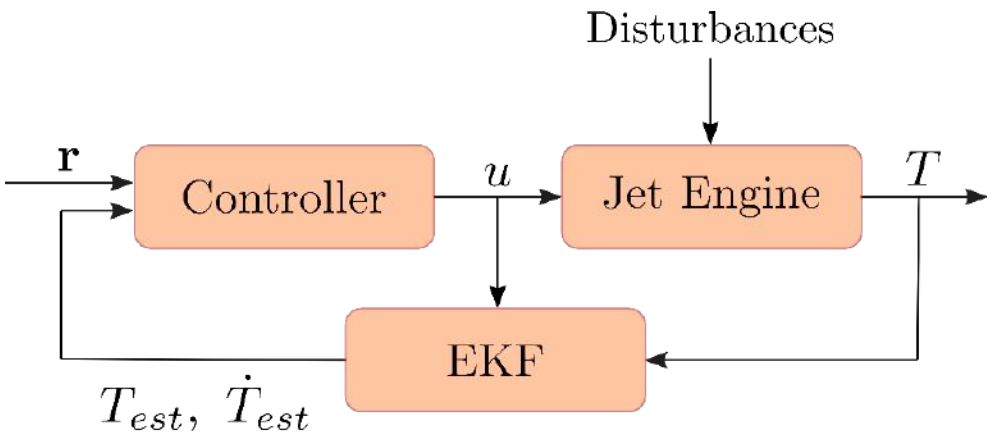
L'Erario et al. "Modeling, Identification and Control of Model Jet Engines for Jet Powered Robotics", IEEE RA-L 2020

JET ENGINE CONTROL

Control objective:

- track a given thrust reference **r**

$$\mathbf{r} = \begin{bmatrix} T_\mathrm{d} & \dot{T}_\mathrm{d} & \ddot{T}_\mathrm{d} \end{bmatrix}$$



FEEDBACK LINEARIZATION CONTROL

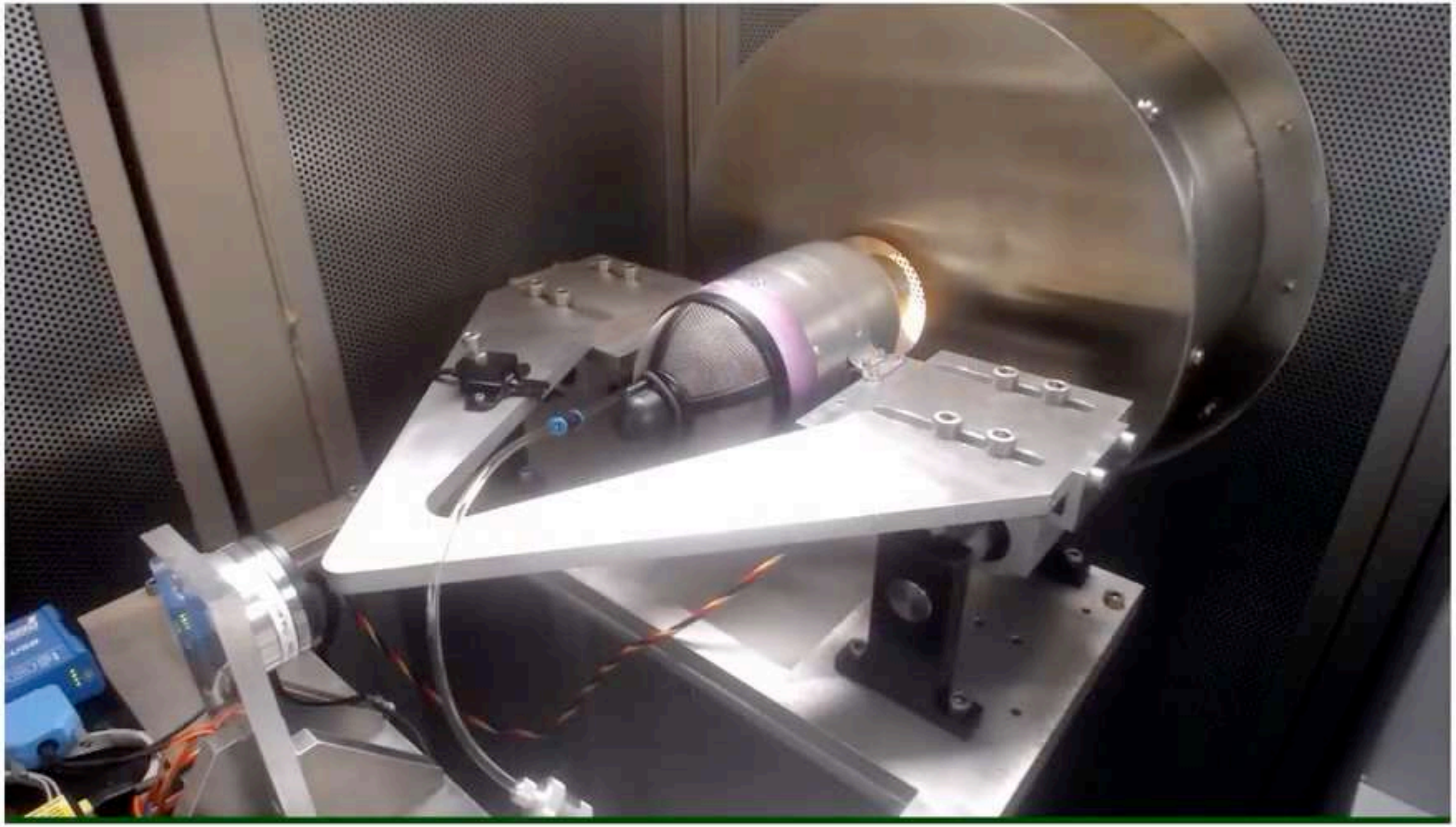
- easy to design
- it may be not robust w.r.t. model uncertainties

SLIDING MODE CONTROL

- robust control technique
- it may generate the *chattering*

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

JET ENGINE CONTROL



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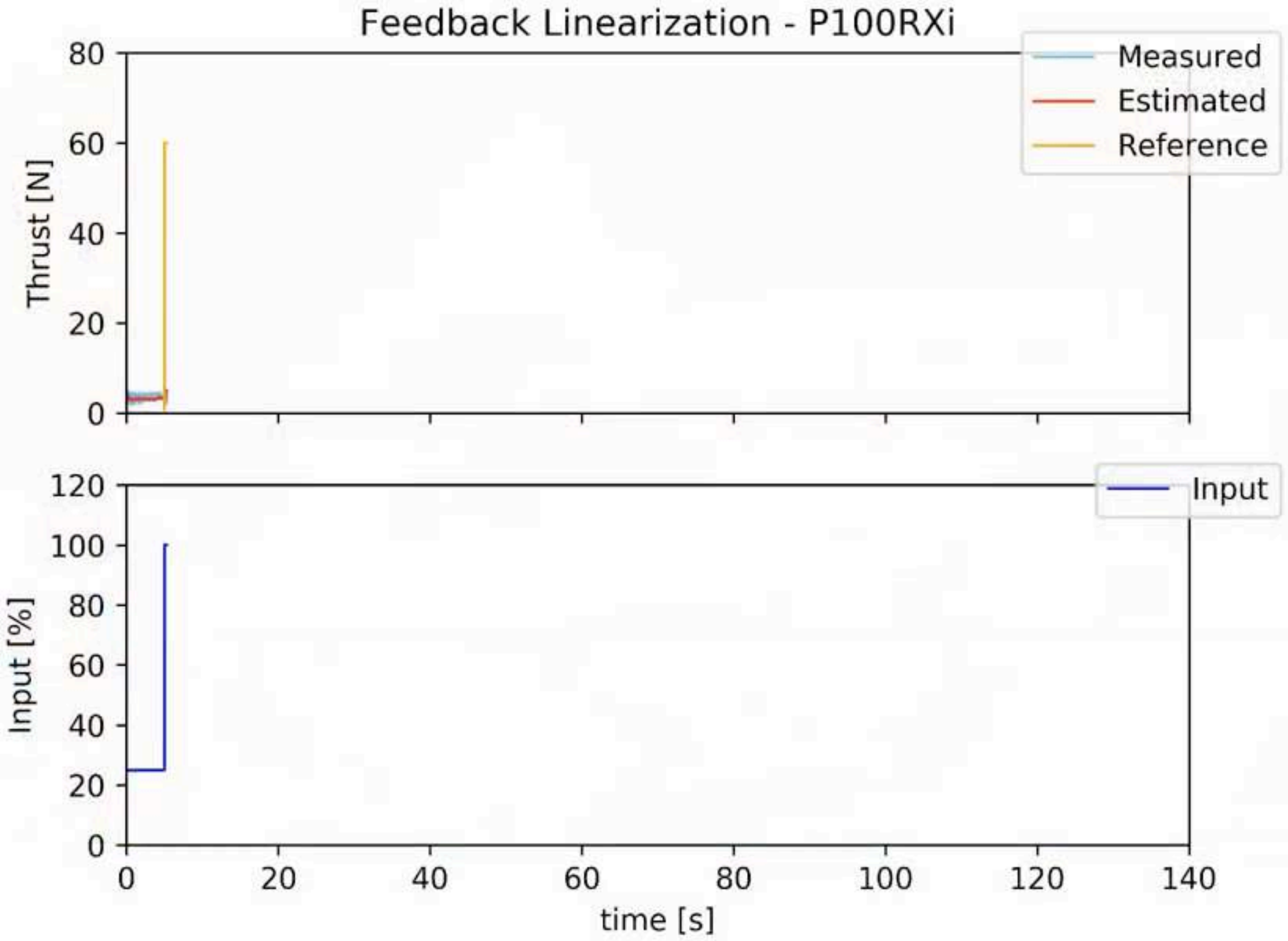
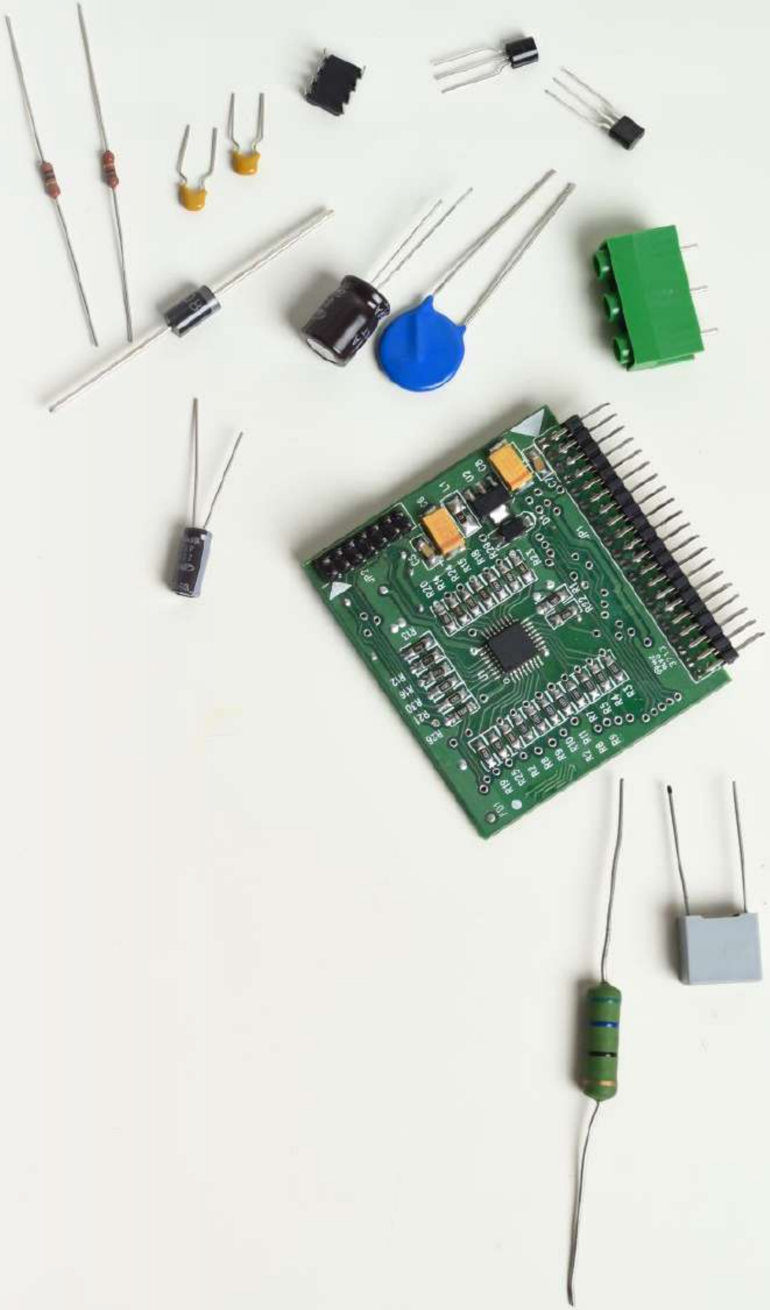
JET ENGINE CONTROL



x10

Mechanics and Electronics



INTRODUCTION

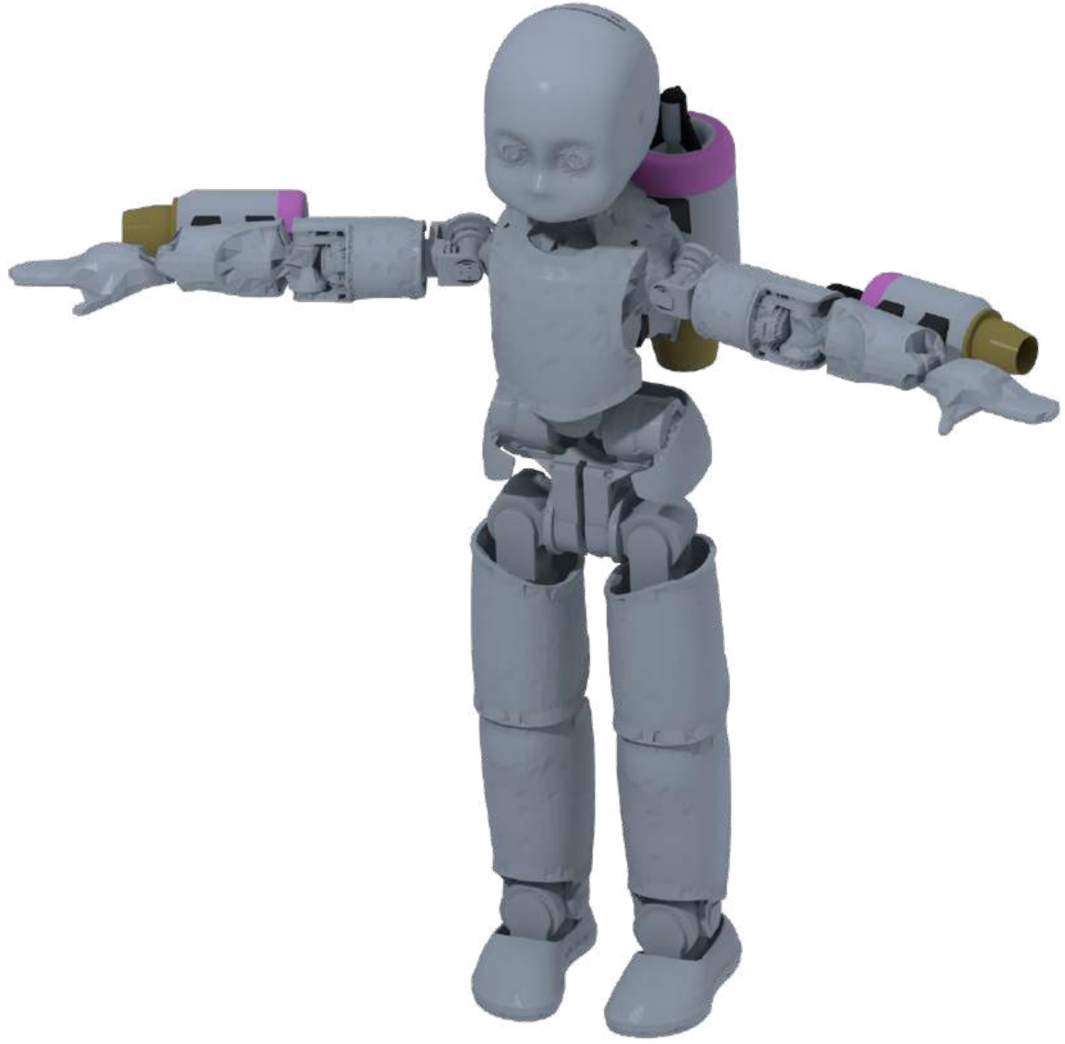
Develop the iRonCub, the first aerial humanoid robot

Robot:

- iCub (53 dof, 33 kg)

Actuations:

- Two P220-Rxi turbines in the back
- One P100-Rx turbine for each arm



INTRODUCTION

INITIAL ASSUMPTION

- Robot battery off board
- Robot communication through lan
- Fuel tank off board

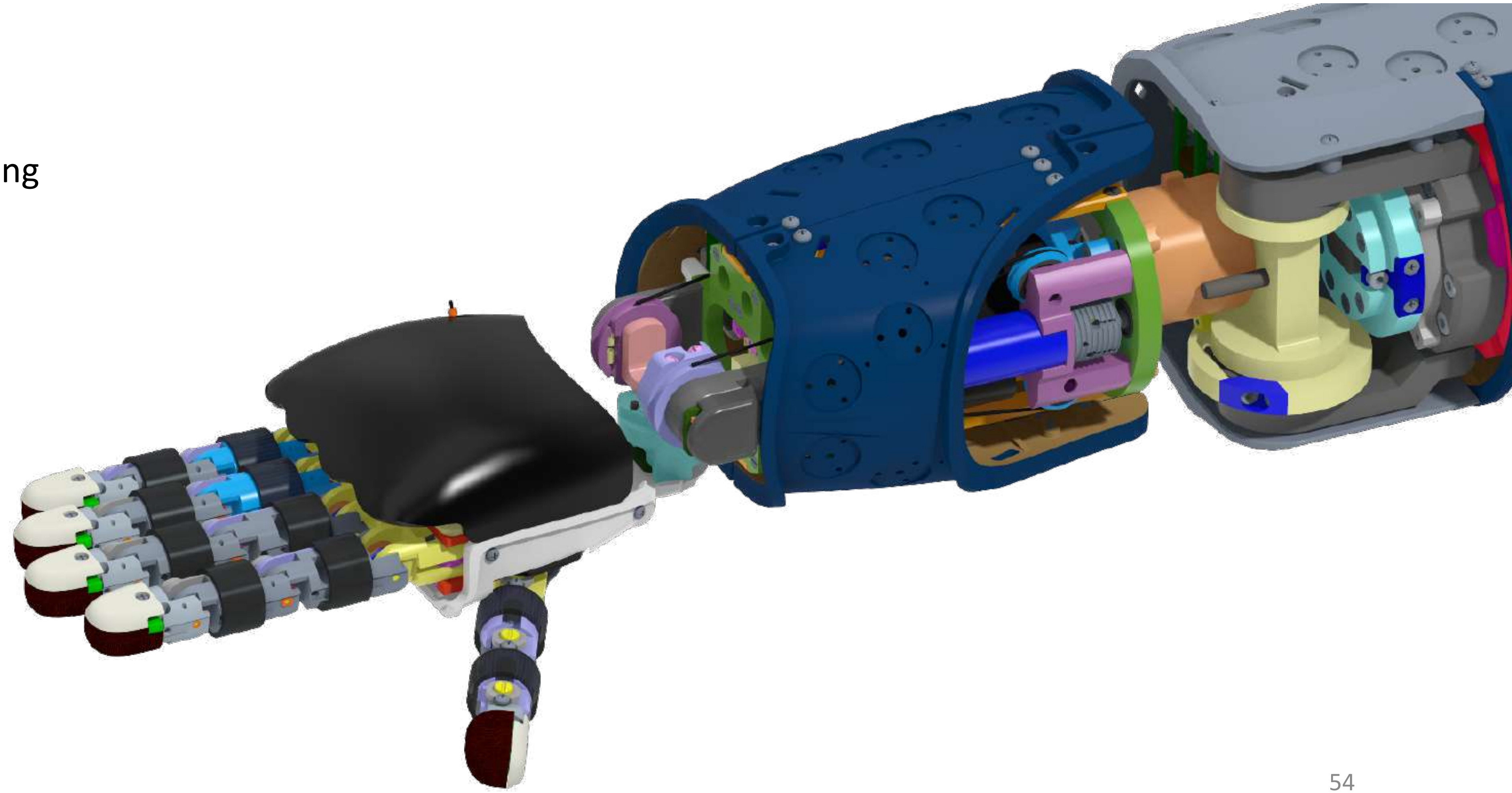
Fuel consumption (full load) 2.2 l/min

Jet engine model	P100-RX	P220-RXi
Nominal Max. Thrust	100 N	220 N
Fuel consumption - full load	390 ml/min	725 ml/min
Weight	1080 g	1850 g
Length	241 mm	307 mm
Diameter	97 mm	116.8 mm

FOREARM
ICUB

Requirements:

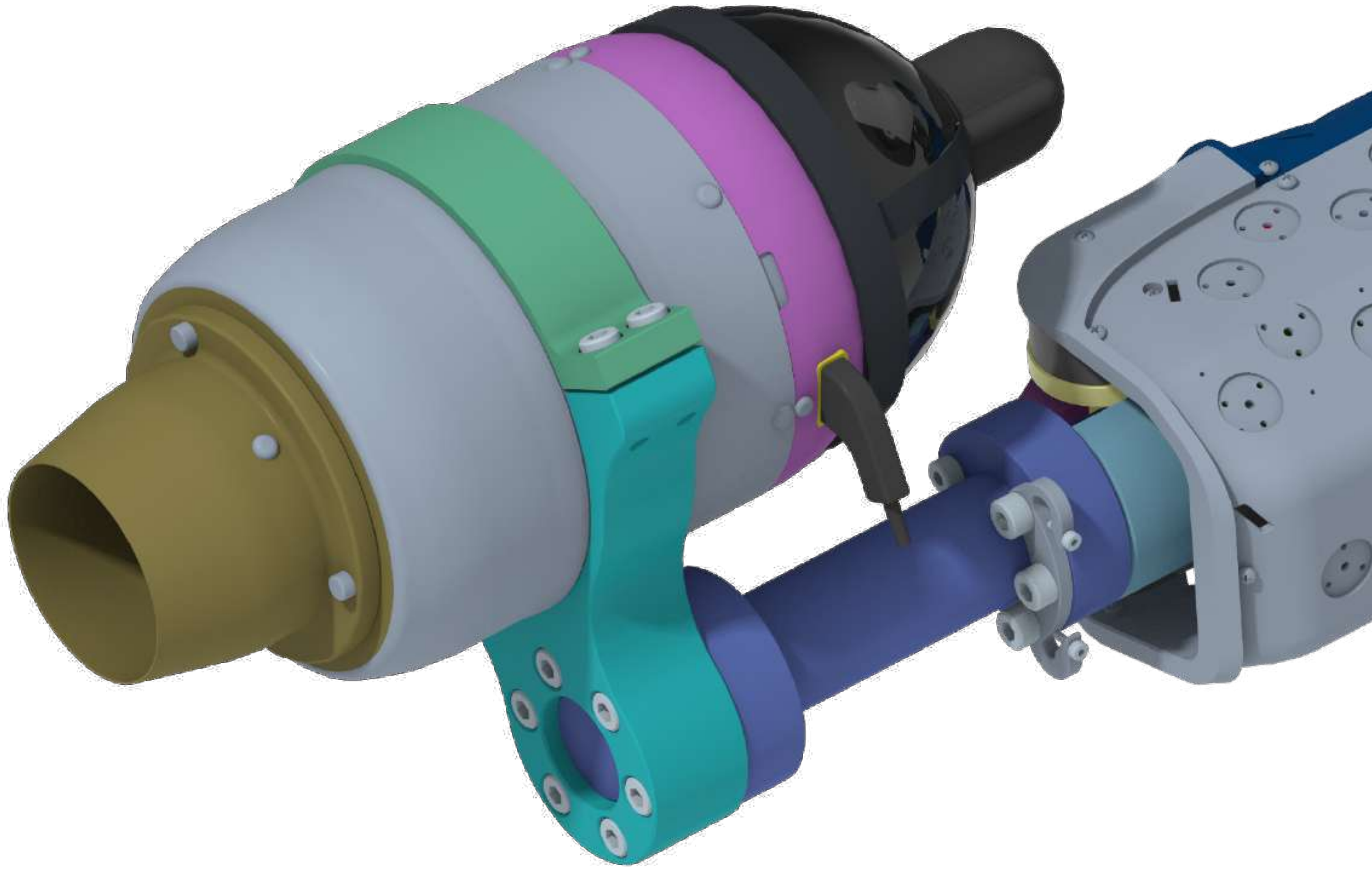
- Fast assembly
- Low time to engineering



FOREARM
SOLUTION

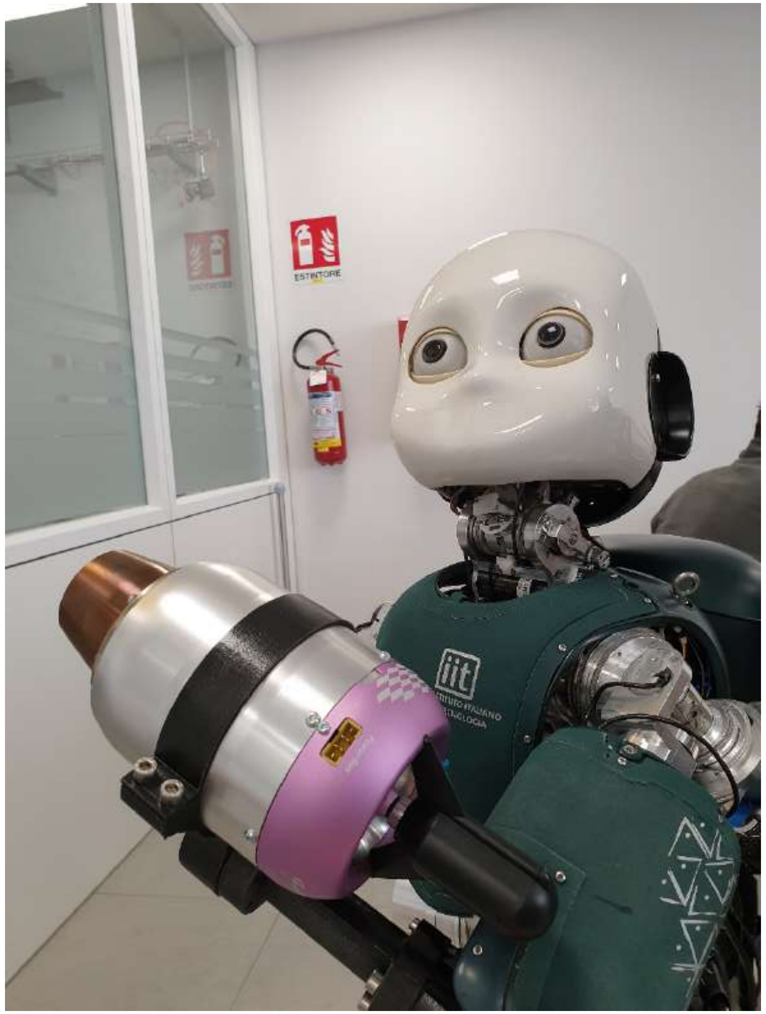
Requirements:

- Fast assembly
- Low time to engineering



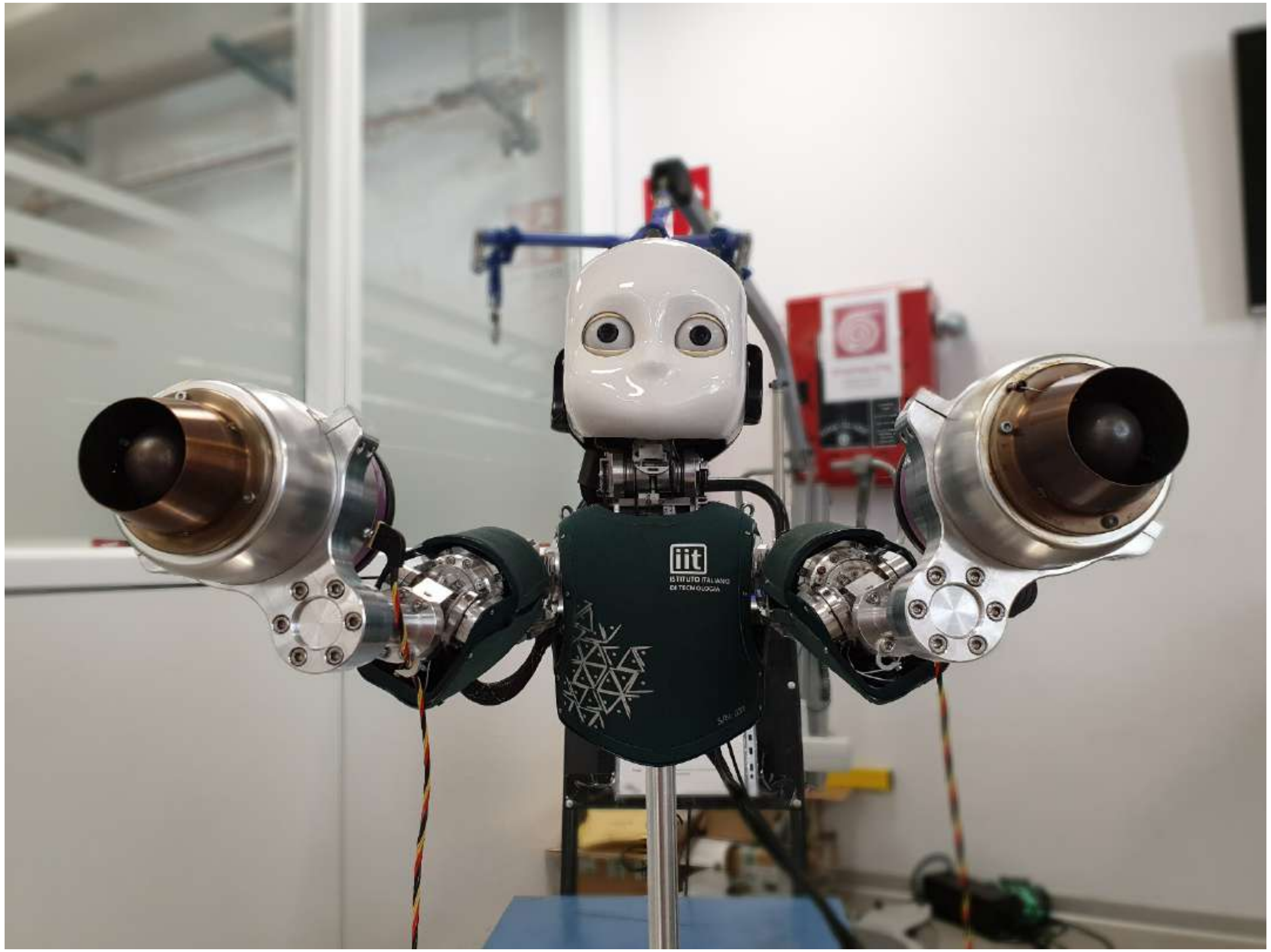
FOREARM

RAPID PROTOTYPING



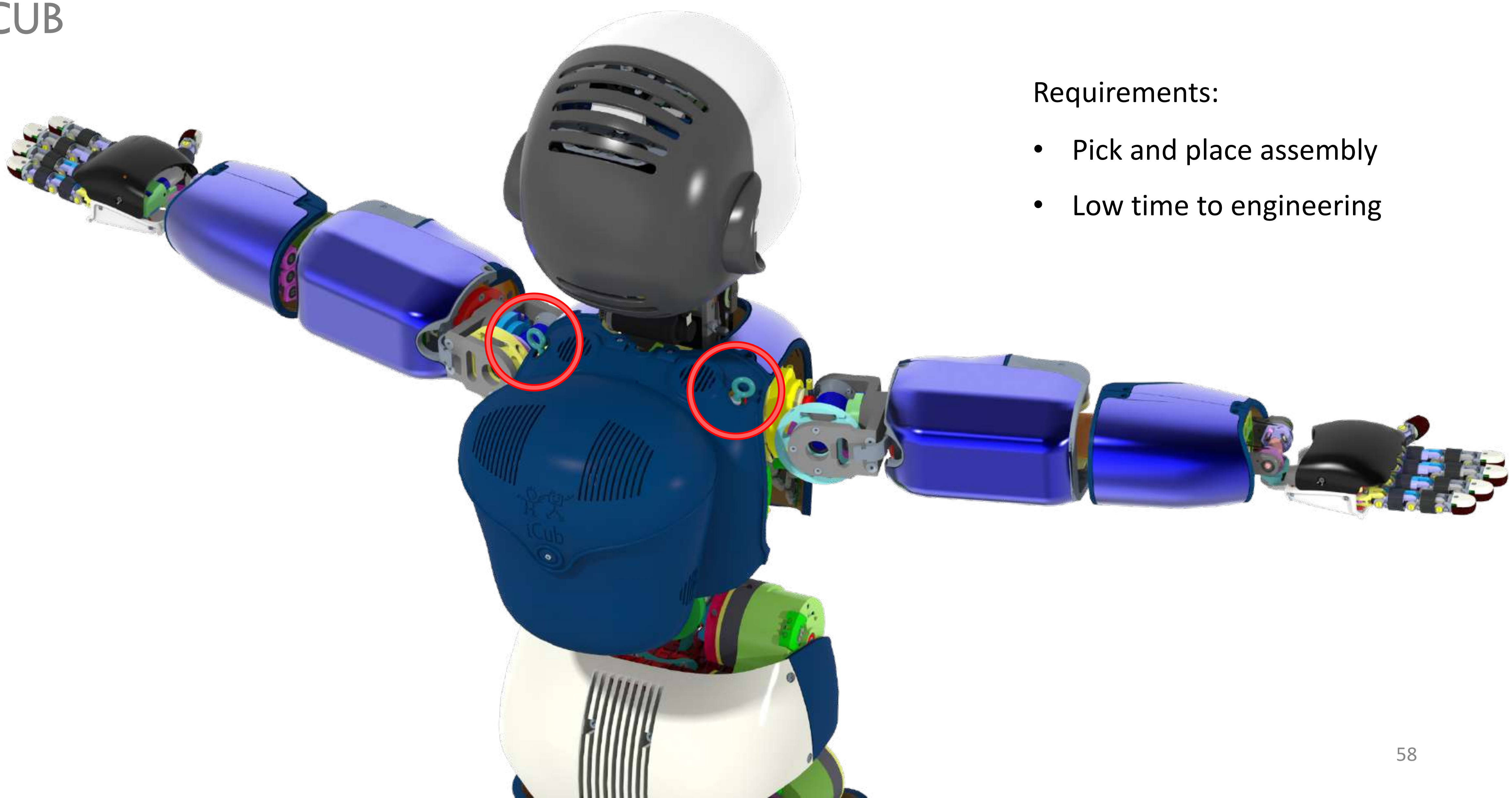
FOREARM

IRONCUB



JETPACK

ICUB



Requirements:

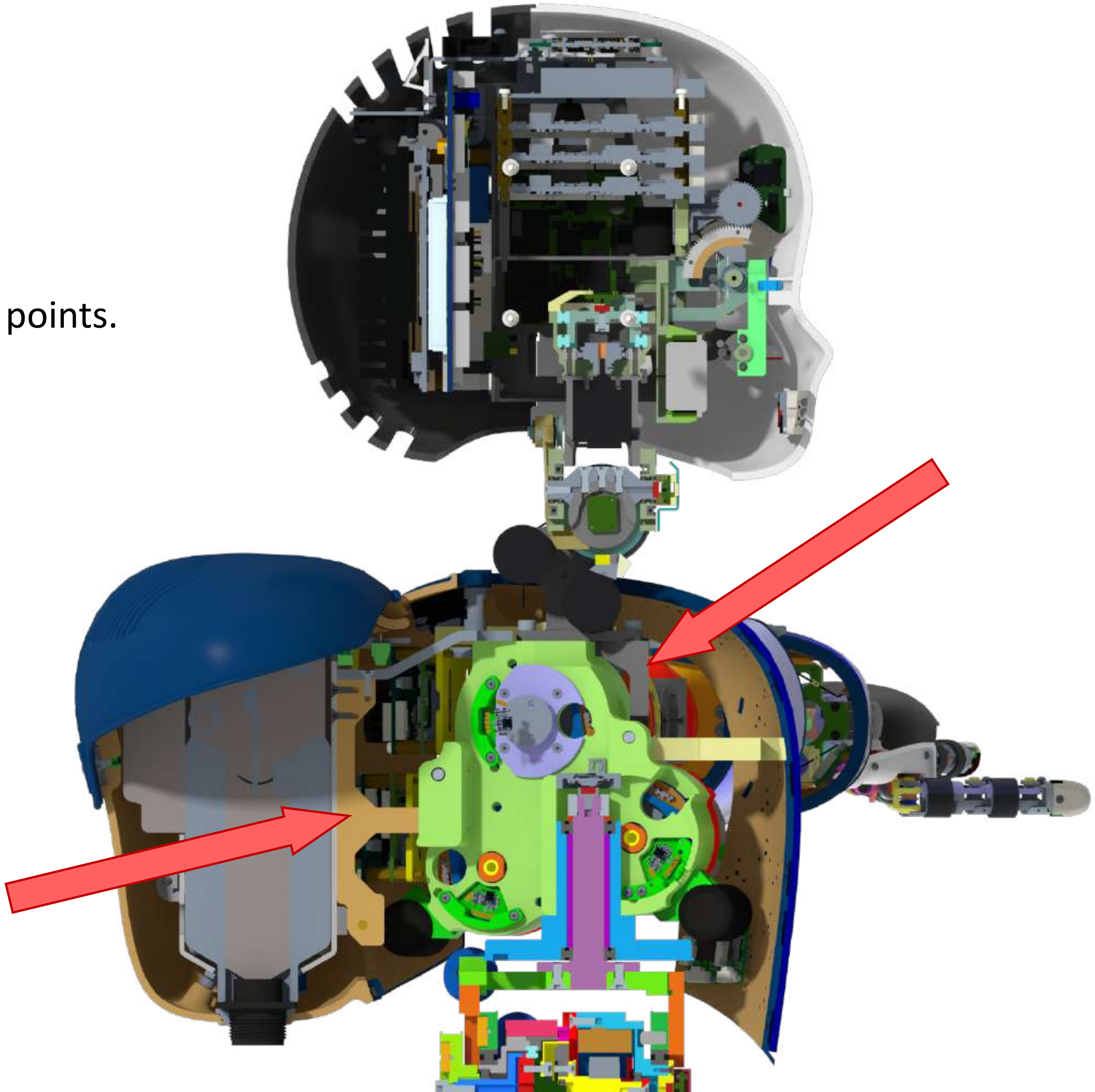
- Pick and place assembly
- Low time to engineering

JETPACK

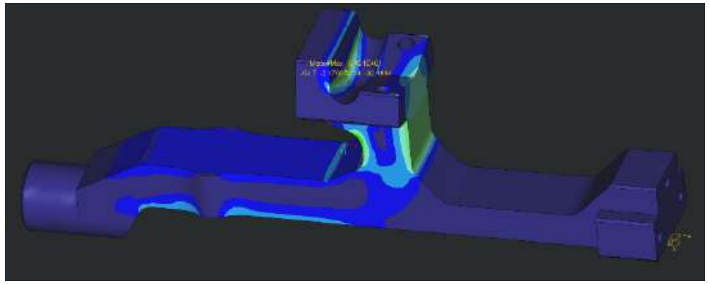
ICUB

There are two connection points.

Let’s find another one



JETPACK
IDEA

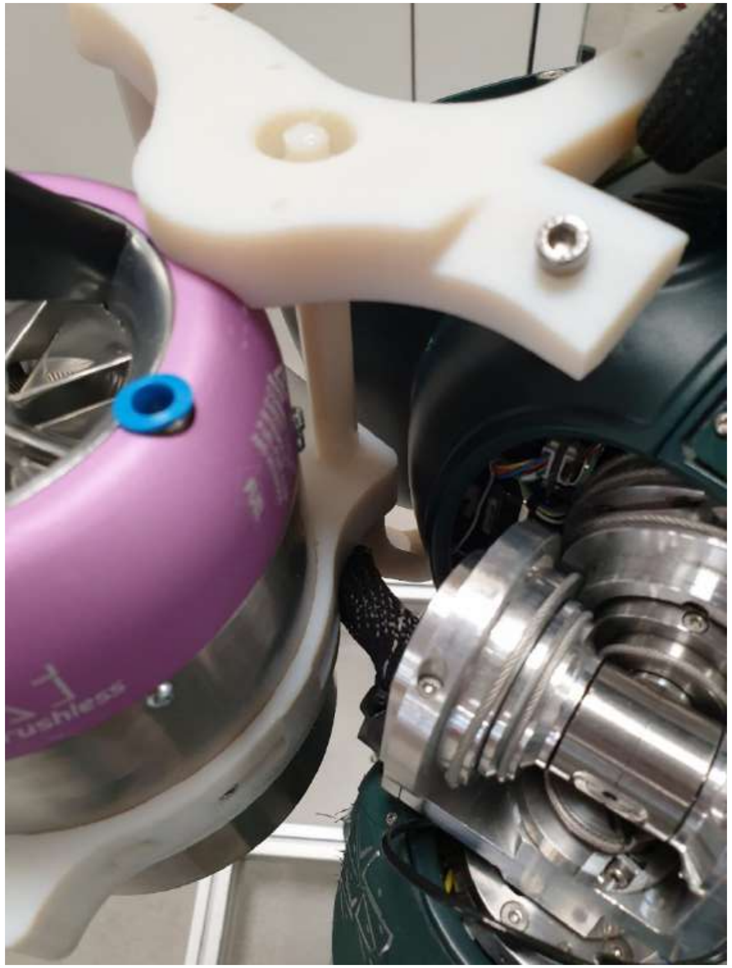


JETPACK

IDEA

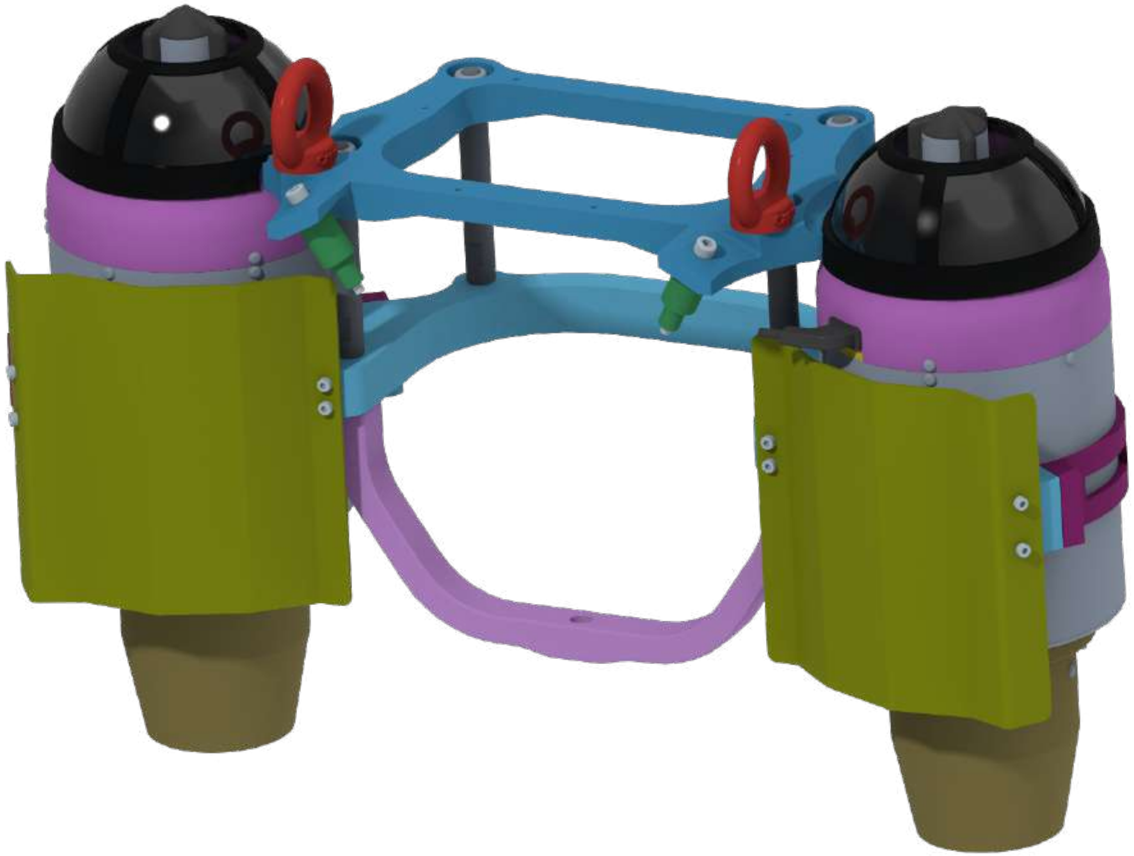
JETPACK

RAPID PROTOTYPING



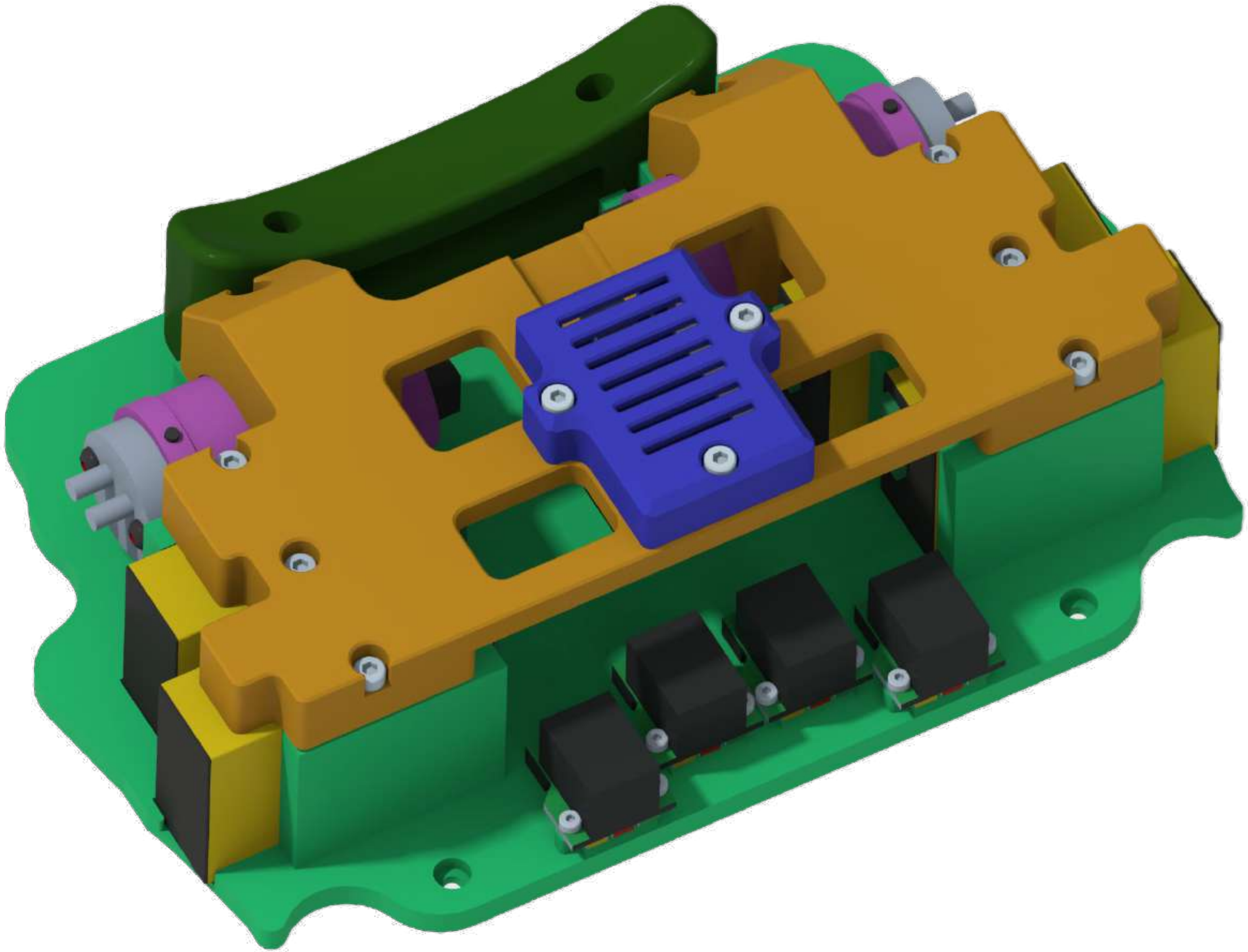
JETPACK

WIRE COVERING PROBLEM



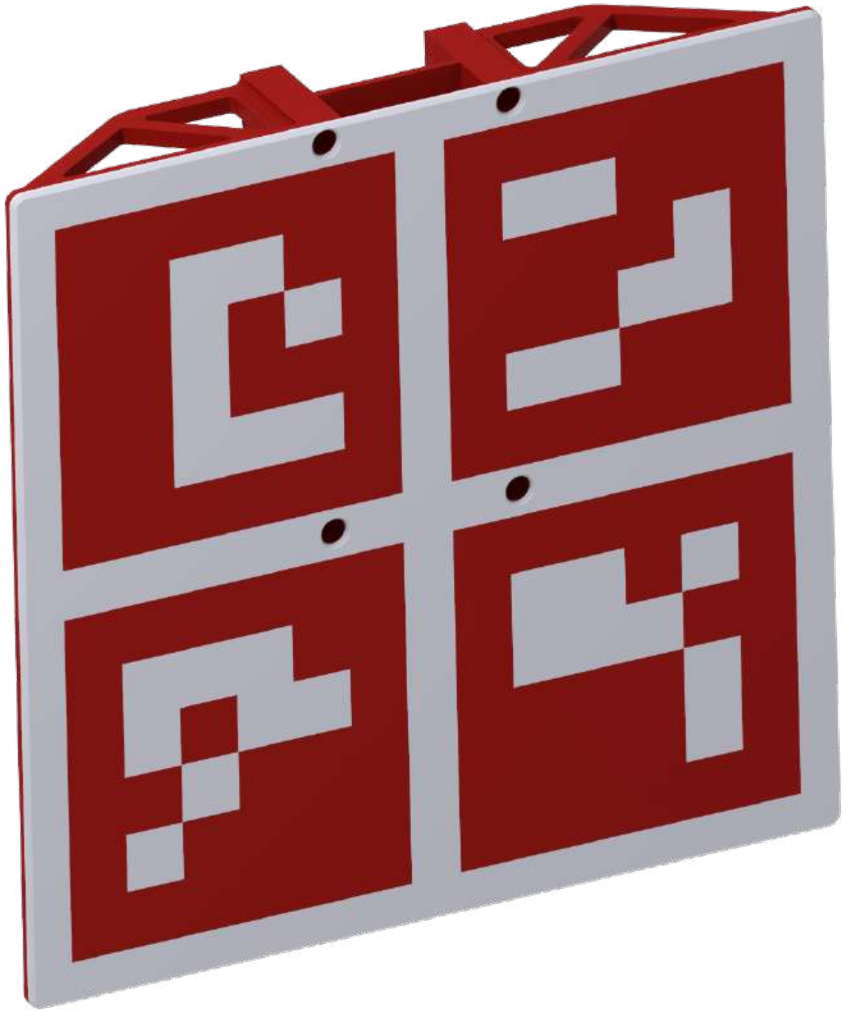
JETPACK

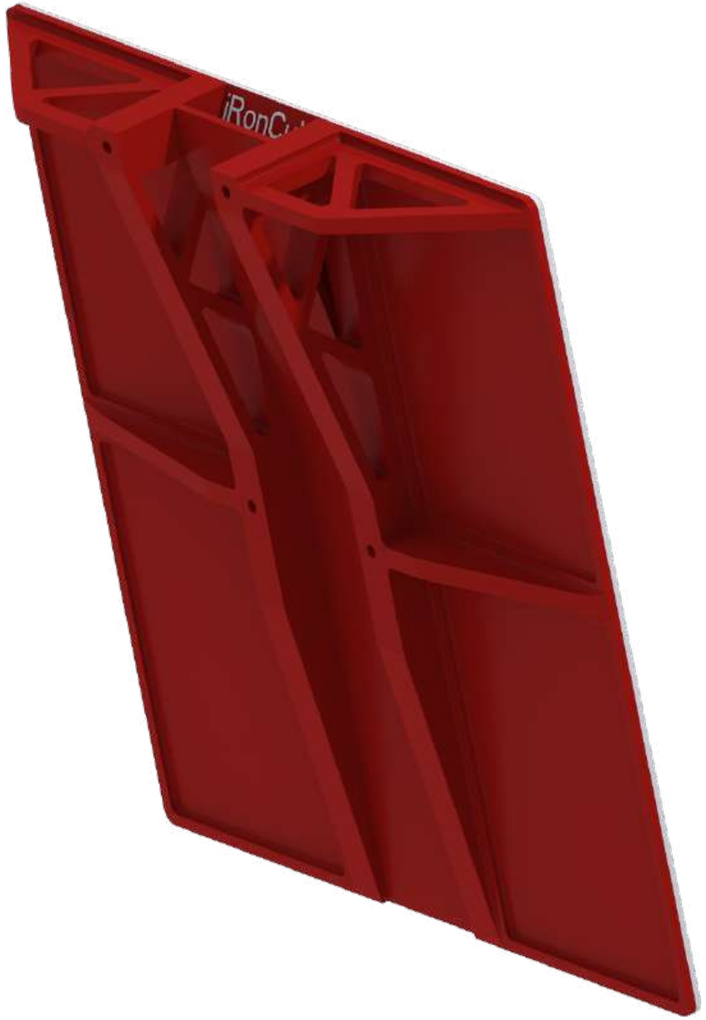
ELECTRONICS



JETPACK

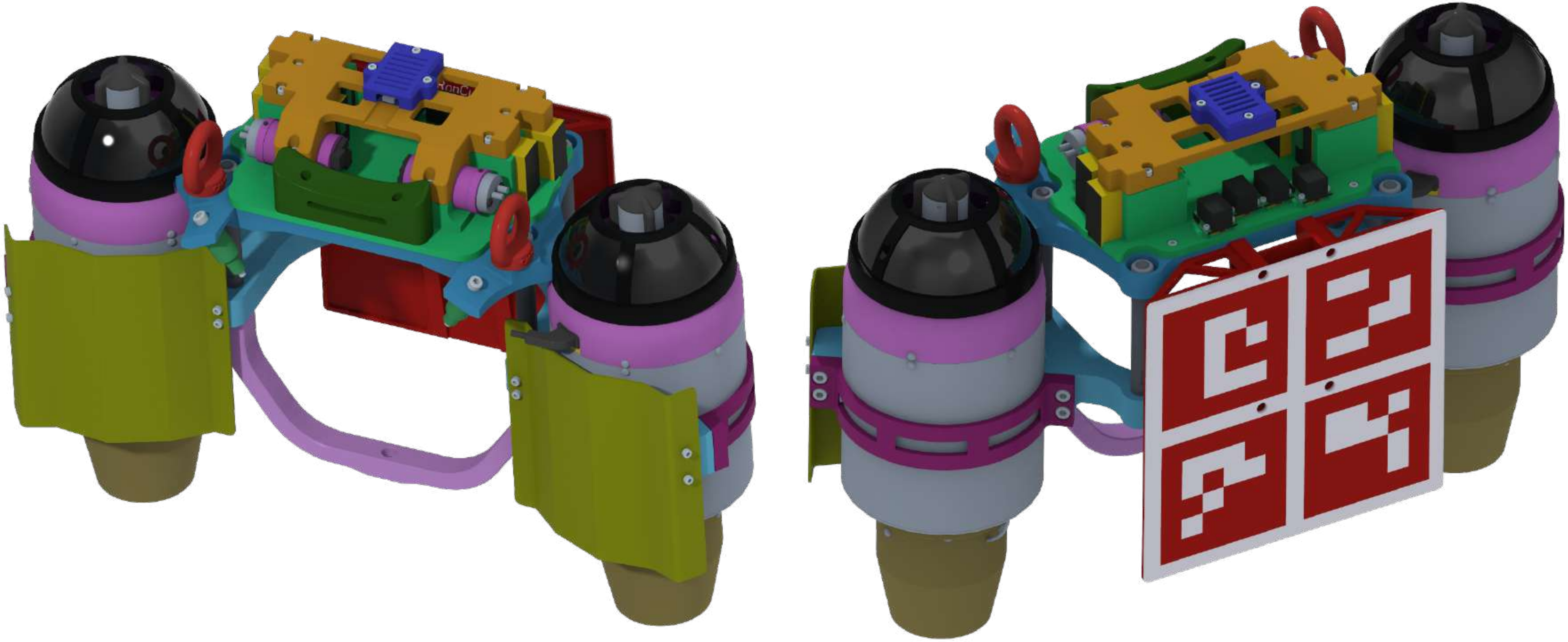
ARUCO



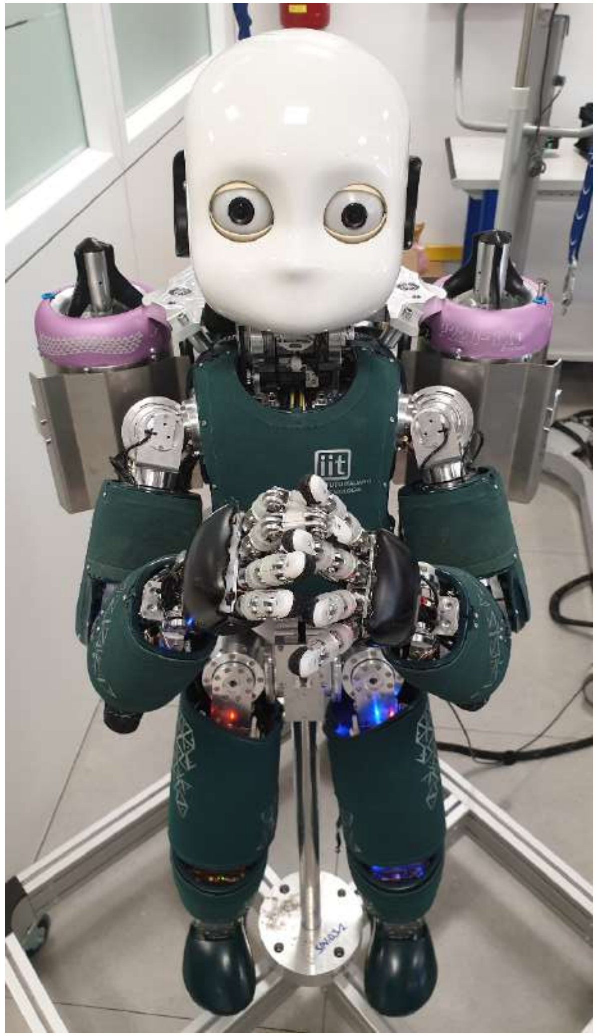


JETPACK

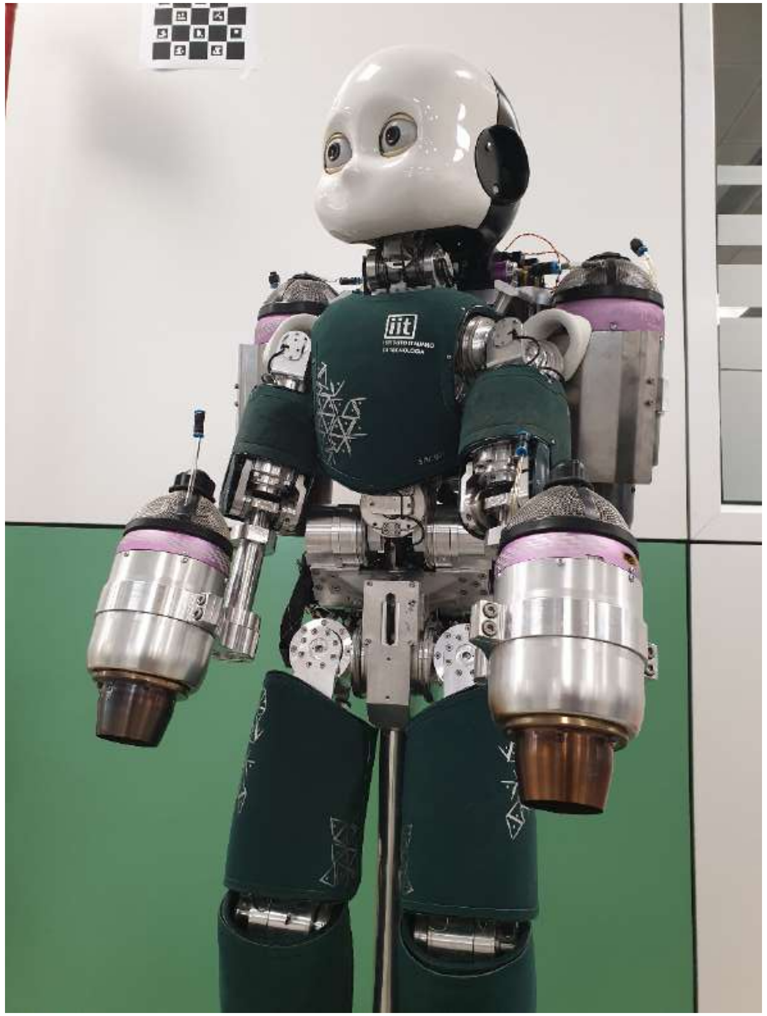
FINAL SOLUTION

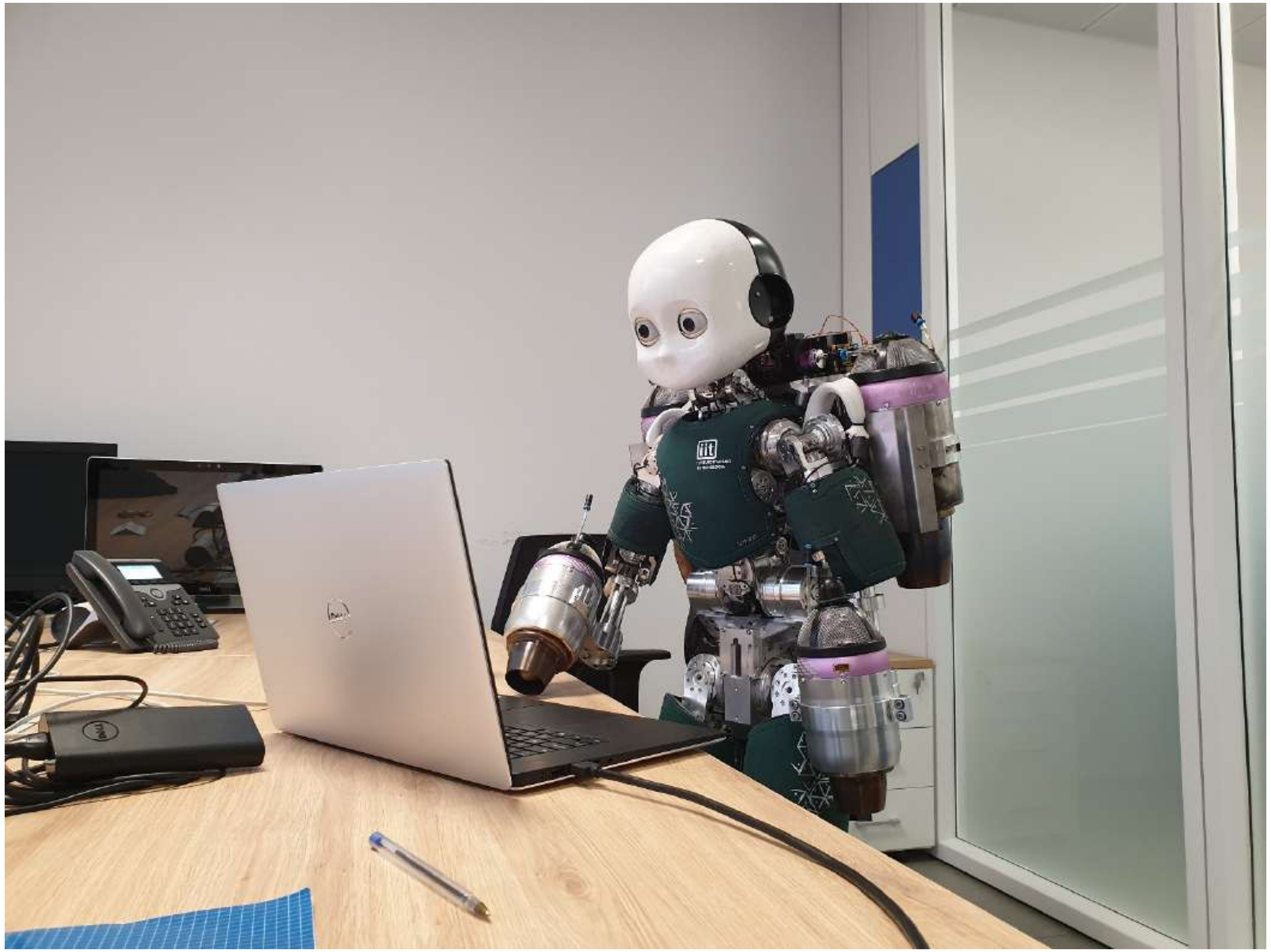


JETPACK
IRONCUB

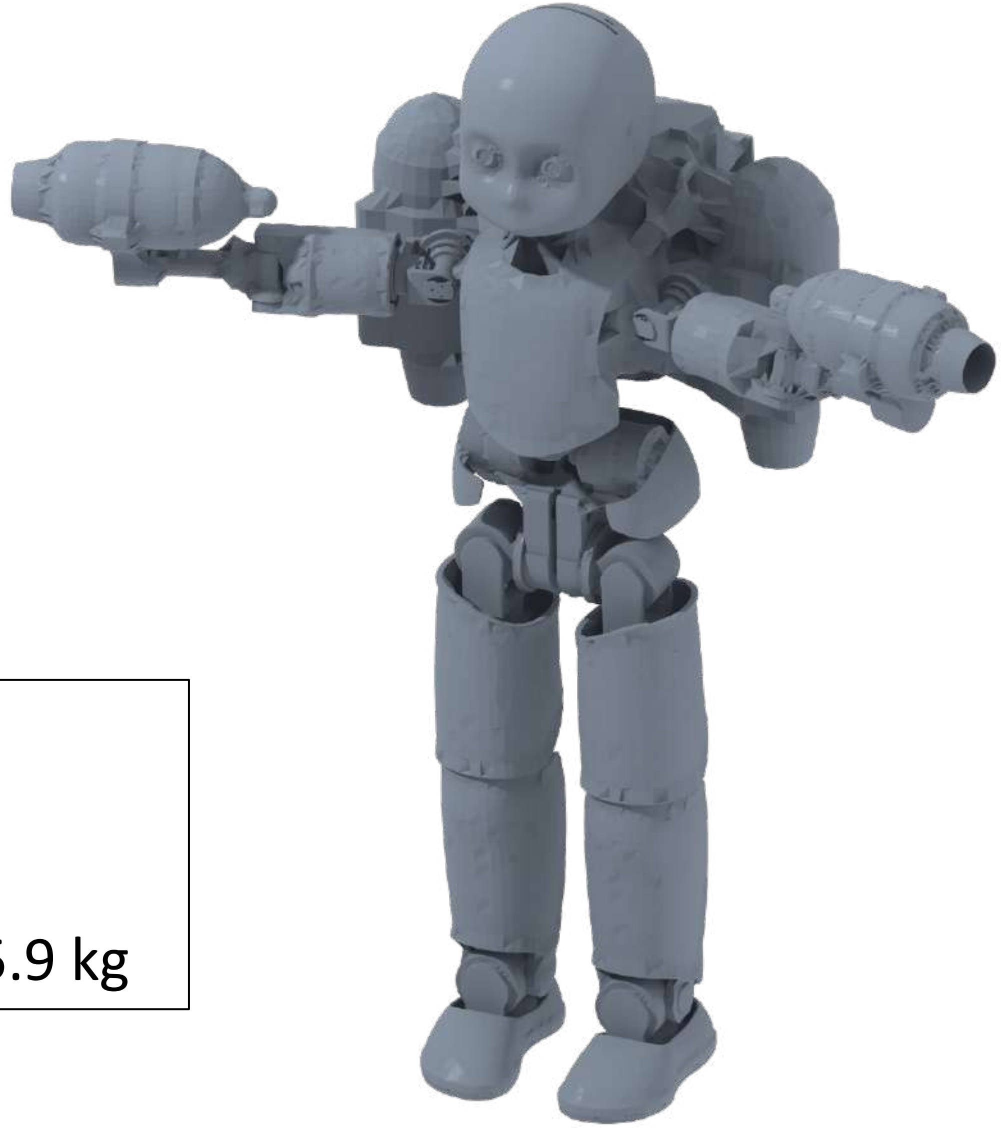



IRONCUB MK1



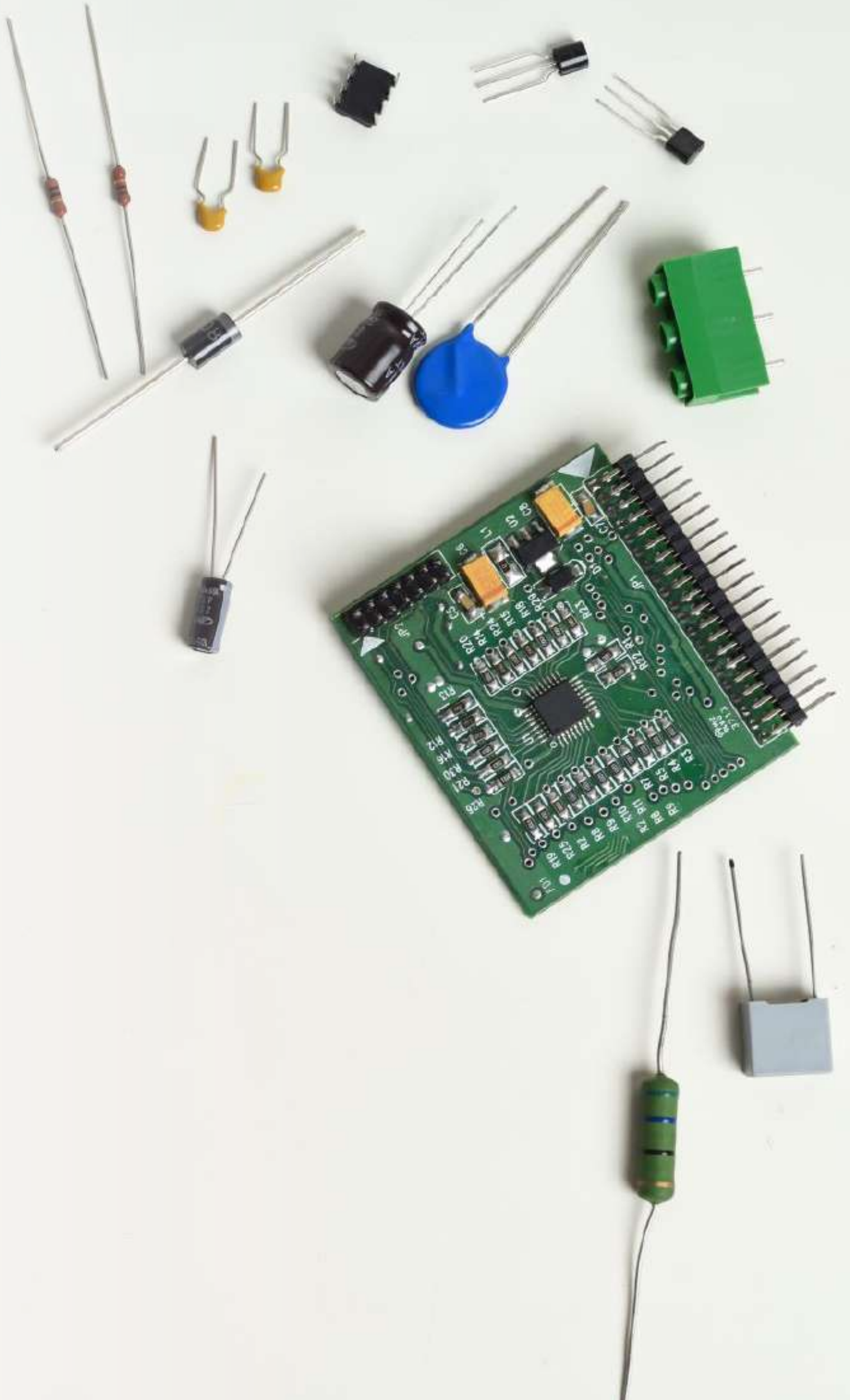


URDF MODEL



Total Mass	41.5 kg
iCub Mass	33.1 kg
iCub no arm	30.7 kg
Turbines Mass	5.9 kg

Body Control & Experiments



IRONCUB FLYING CONTROL

THE MAIN APPROACH

BEHAVIOURS = MODEL + OPTIMIZATION

Bioinspiration of little help

IRONCUB FLYING CONTROL

MODELING

$$f = ma$$

$$M(q)\dot{\nu} + C(q,\nu)\nu + g(q) = \begin{pmatrix} 0_6 \\ \tau \end{pmatrix} + J^T F$$

$$q \in SE(3) \times \mathbb{R}^n \qquad \nu \in se(3) \times \mathbb{R}^n$$

IRONCUB FLYING CONTROL

OPTIMISATION

Instantaneous optimisation

$$\text{Inputs}^* = \underset{\text{Inputs}}{\text{argmin}} \;\; \text{Cost-functions(Inputs,Model)}$$

subject to

Constraints

Predictive optimisation

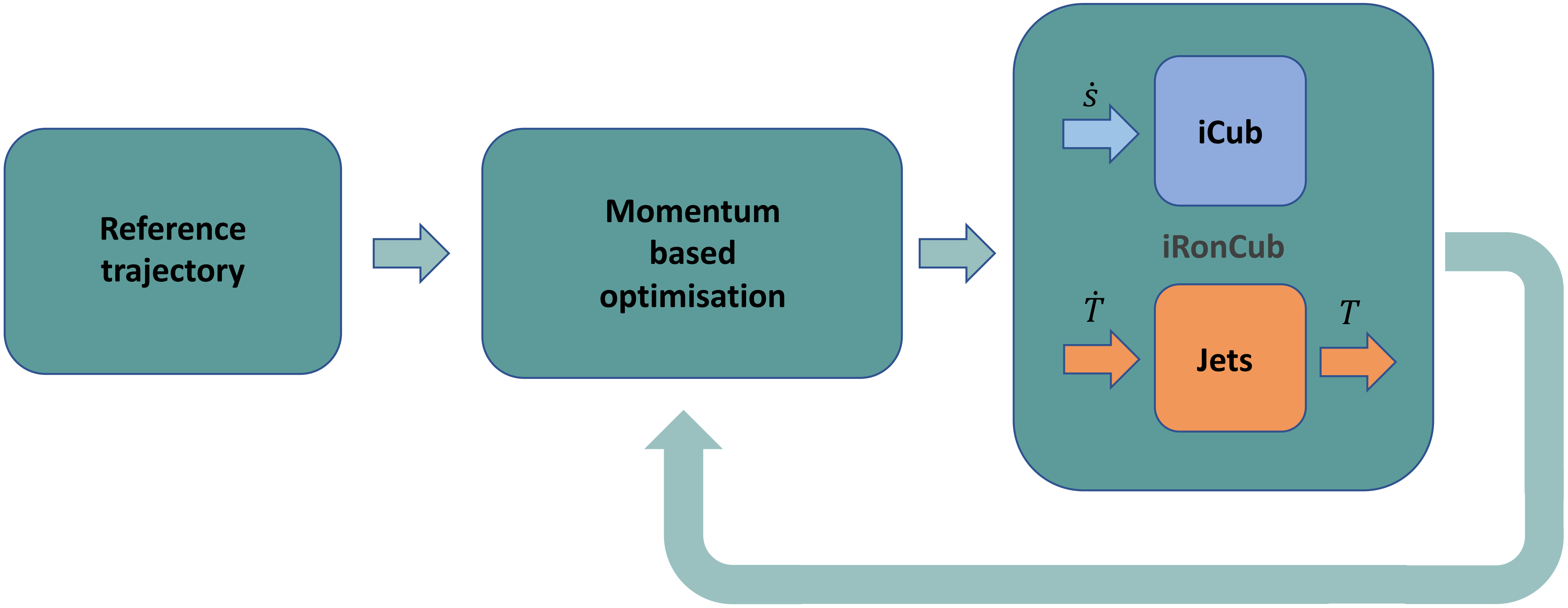
$$\text{Inputs}^* = \underset{\text{Inputs}}{\text{argmin}} \int_{t_{0_k}}^{t} \text{Cost-functions(Inputs,Model)}\,dt$$

subject to

Constraints

IRONCUB FLYING CONTROL

SIMULATION CONTROL SCHEME



Pucci et al. "Momentum Control of an Underactuated Flying Humanoid Robot" IEEE RA-L, 2017

IRONCUB FLYING CONTROL

Control objective:

Asymptotic stabilization of the robot **centroidal momentum**.

Momentum task and Postural task achieved using **Quadratic Optimization**.

Momentum based optimisation

Pucci et al. "Momentum Control of an Underactuated Flying Humanoid Robot" IEEE RA-L, 2017
Nava et al. "Position and attitude control of an underactuated flying humanoid robot" IEEE Humanoids, 2018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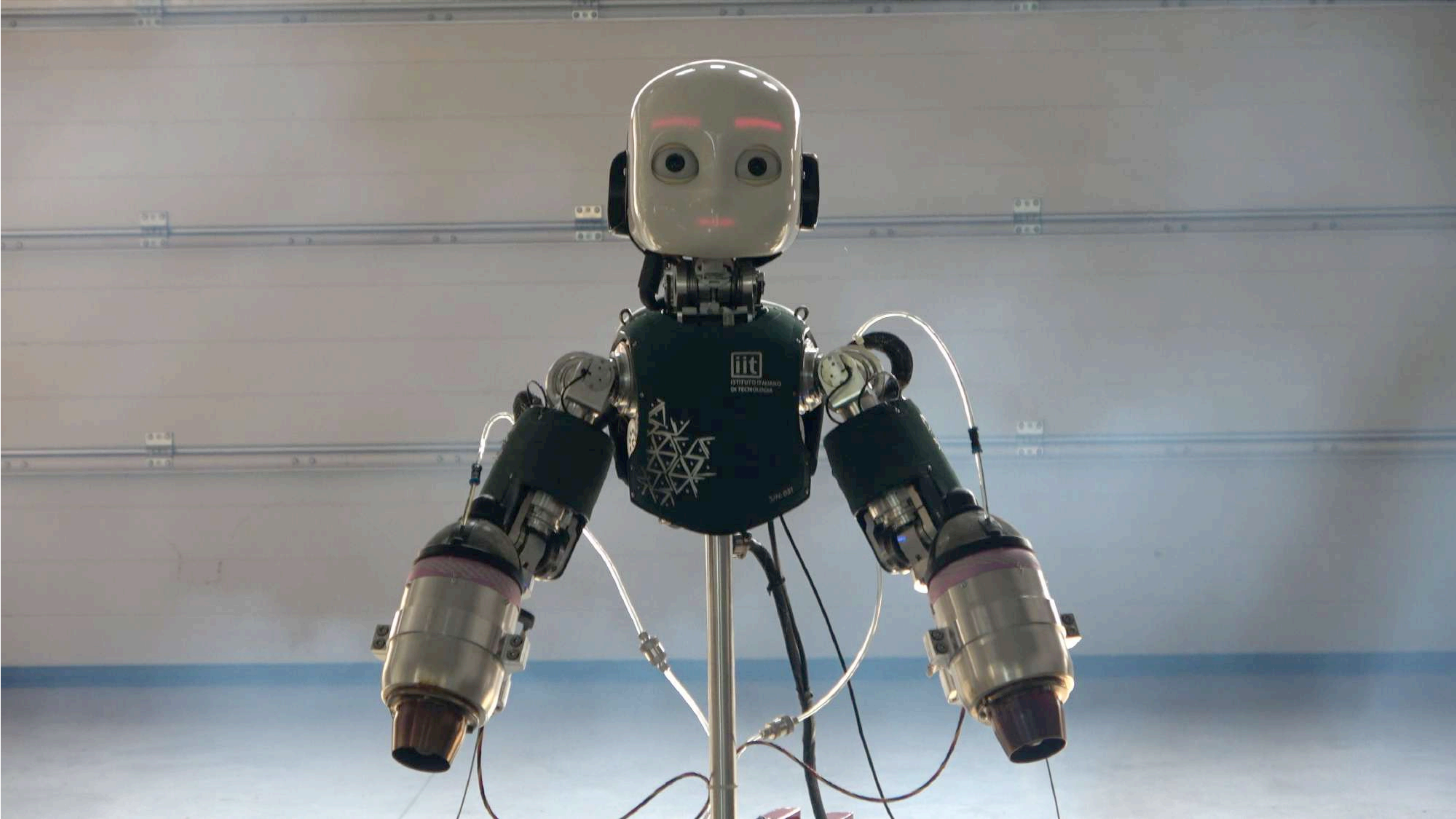
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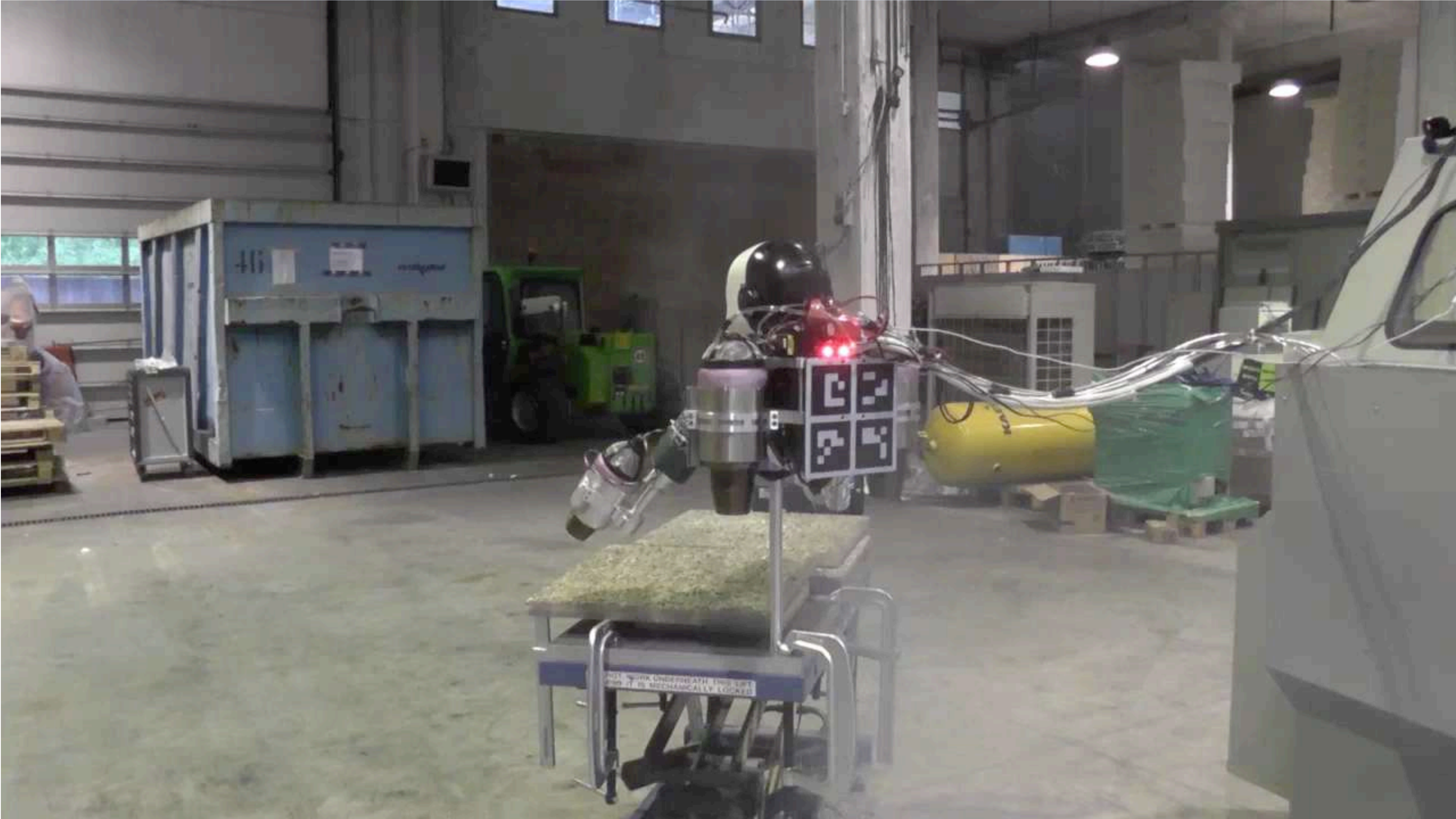
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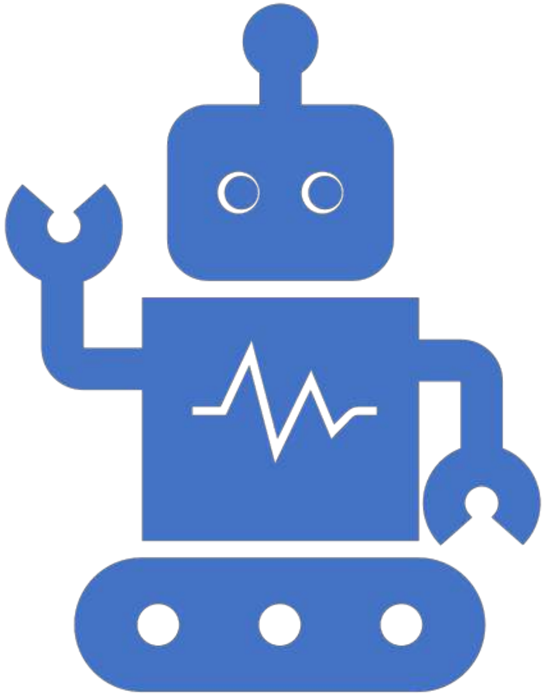
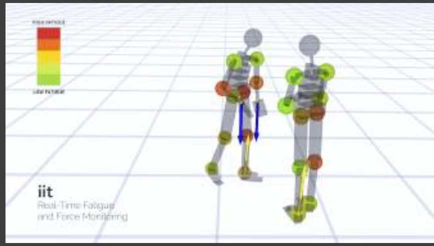


How do we design and control the next generation of humanoid robots that act and locomote in anthropomorphic environments?



Latella et al. "Simultaneous Floating-Base Estimation of Human Kinematics and Joint Torques" Sensors, 2019

The lab investigates also pHRI aspects with humanoid robots

Rapetti et al. "Shared Control of Robot-Robot Collaborative Lifting [..]" IEEE ICRA (submitted), 2020

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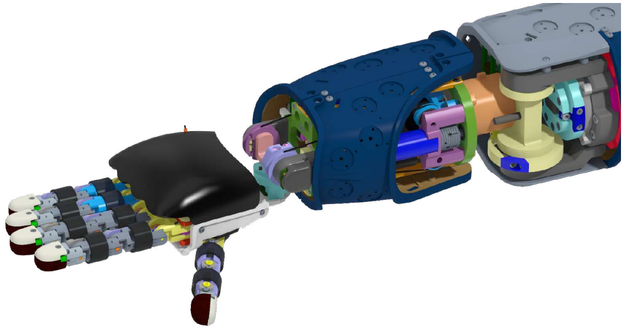

What if the covers could change their shapes?

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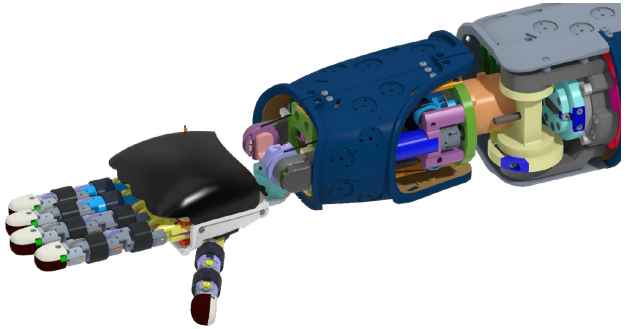

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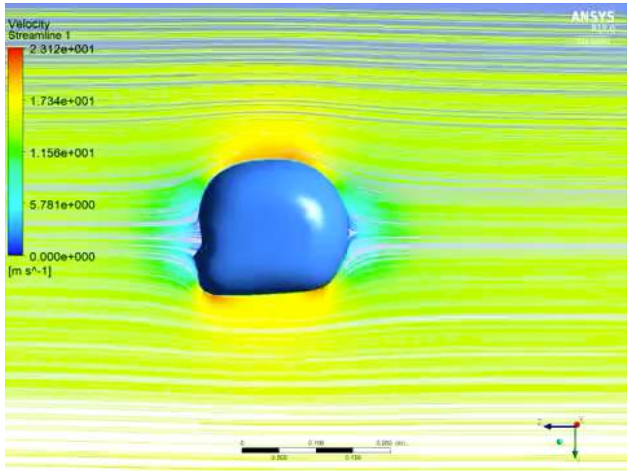

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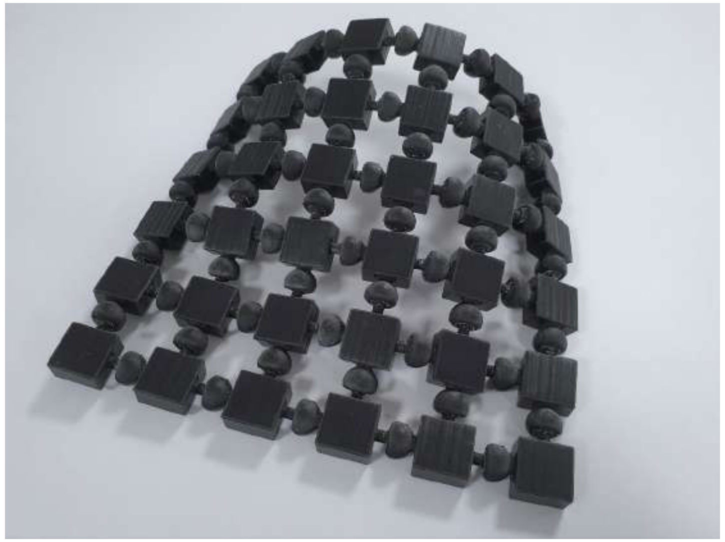

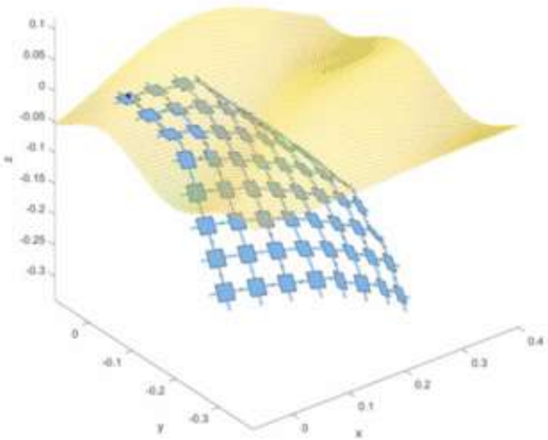

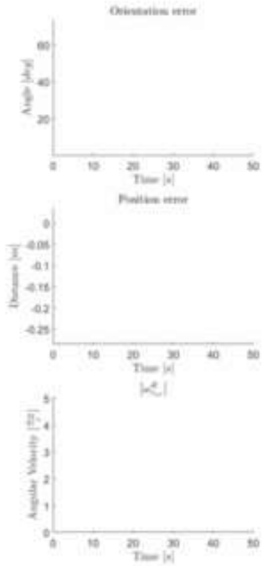

- Genetic Algorithms for actuator positioning
- Control of highly parallel structure

Bergonti et al. "Kinematic Modeling and Control of Morphing Covers for Humanoid Robots" (to be submitted), IEEE RA-L

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