Drone Garden Workshop 2019

LAAS-CNRS, June 6th, 2019

Interaction with Environment and Mission Planning for UAV -UGV Teams

Stjepan Bogdan

University of Zagreb
Croatia

larics.fer.hr

LARICS

larics.rasip.fer.hr

LARICS – Laboratory for Robotics and Intelligent Control Systems

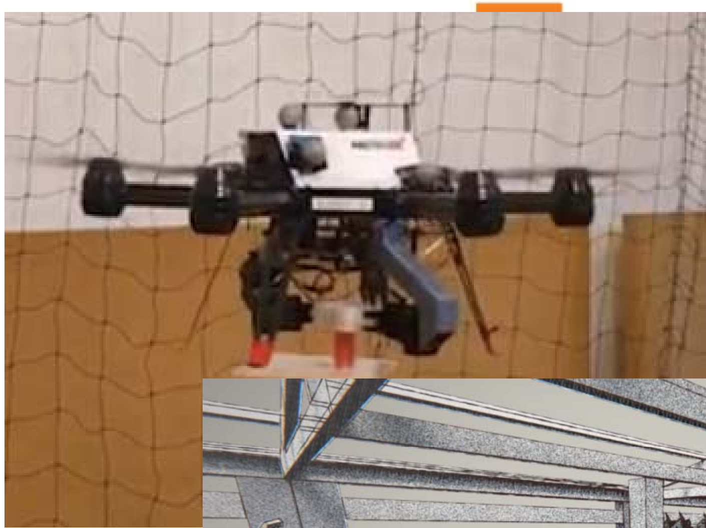
University of Zagreb

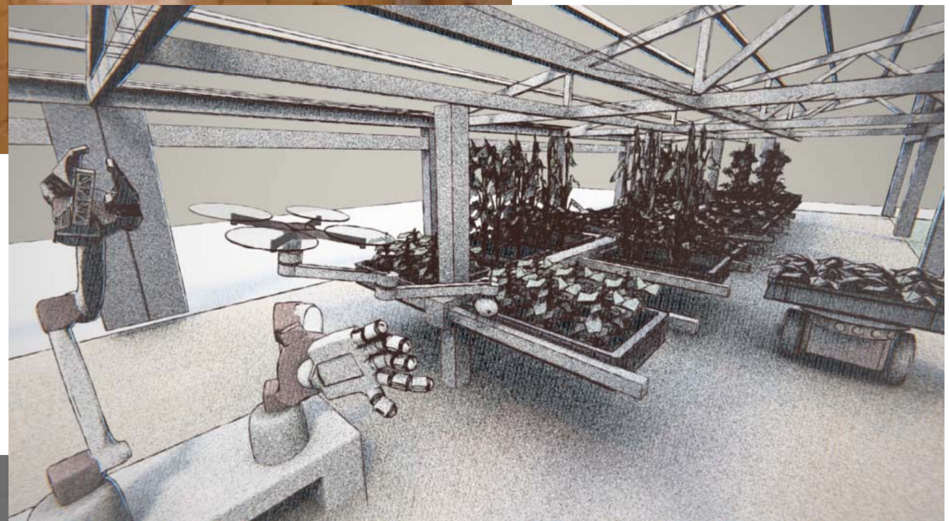
Faculty of Electrical Engineering and Computing

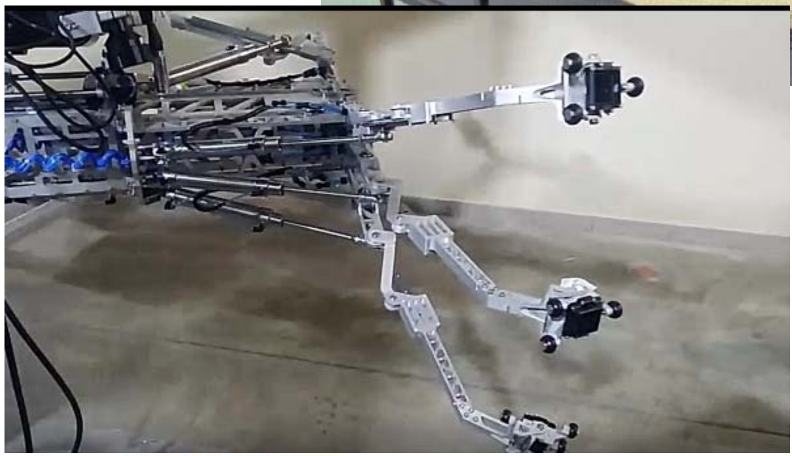
Established in 1996.

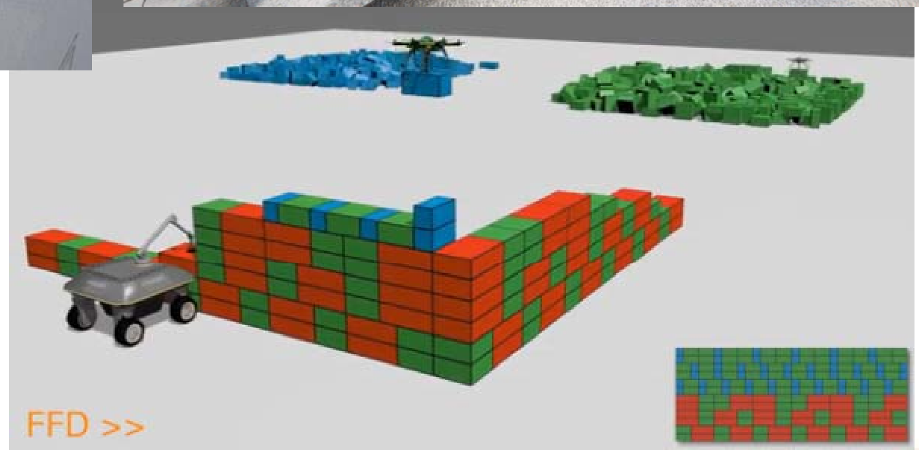
- **20** researchers
  - **4** professors
  - **2** postdocs
  - **14** PhD students
- 70+ students (BS, MS)

- Integrated Robot & Process Control
- Intelligent Control Systems
- Control of Manufacturing Systems
- Multi - agent Systems
- *Aerial Robotics*
- Professional Service Robotics
- Human - Robot Interaction









Aerial robotics projects (current and last 5 years)

Title	Grant	Duration	Budget Total	Budget FER
AeroTwin - Twinning coordination action for spreading excellence in Aerial Robotics	EU H2020	2018 2021	990 k€	290 k€
ENCORE – ENergy aware BIM Cloud Platform in a COst-effective Building REnovation Context	EU H2020	2019 2022	5.5 M€	316 k€
MORUS - Unmanned System for Maritime Security and Environmental Monitoring	NATO SpS	2015 2019	800 k€	115 k€
EuRoC - EOLO: Wind Generator Remote Inspection System	EU FP7	2015 2018	7 M€	270 k€
SPECULARIA – Structured Ecological CULtivation with Autonomous Robots in Indoor Agriculture	HRZZ (CroNSF)	2018 2023	280 k€	280 k€
MBZIRC – The Mohamed Bin Zayed International Robotics Challenge	Khalifa Uni.	2018 2020	140 k€	140 k€

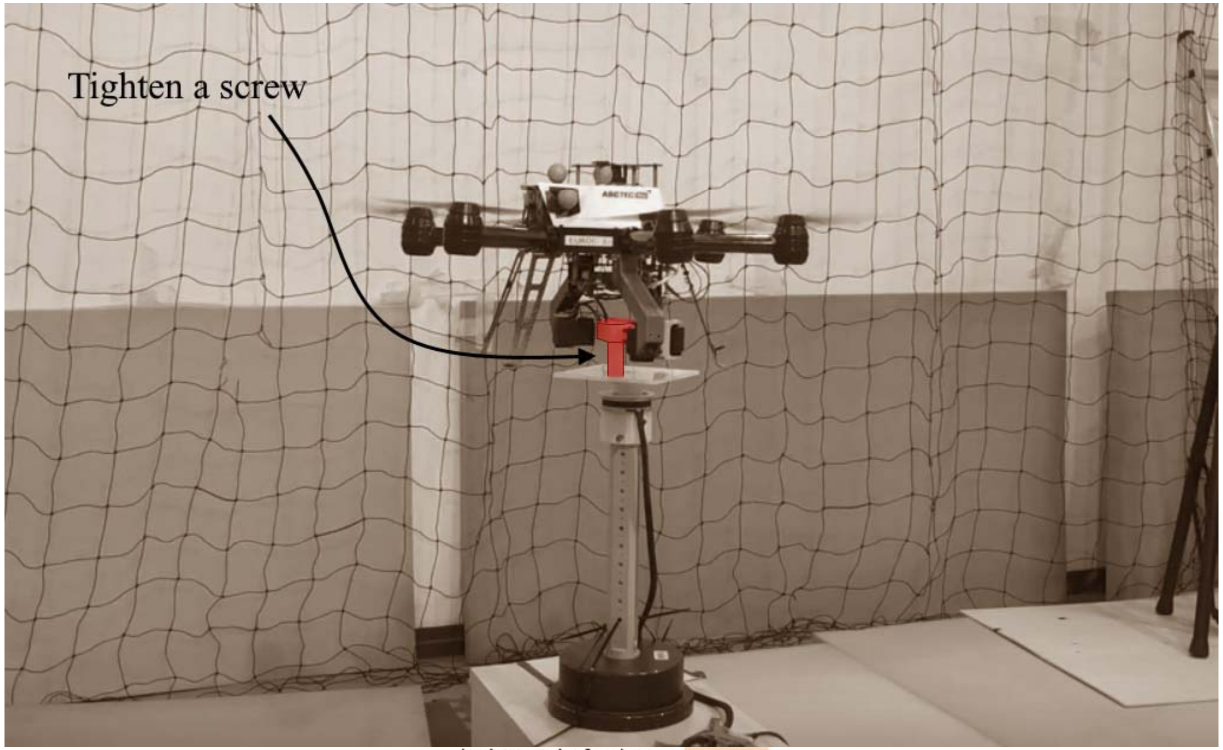
Other major projects (current and last 5 years)

Title	Grant	Duration	Budget Total	Budget FER
ASSISI - Animal and robot Societies Self-organise and Integrate by Social Interaction (bees and fish)	EU FP7	2013 2018	6 M€	760 k€
subCULTron – Submarine Cultures Perform Long-term Robotic Exploration of Unconventional Environmental Niches	EU H2020	2015 2019	4 M€	650 k€
ENDORSE – Effective Robotic GriNDing of Surface Areas through HORSE framework	EU H2020	2018 2019	192 k€	78 k€
ADORE – Autism Diagnostic Observation with Robot Evaluator	HRZZ	2015 2018	150 k€	150 k€
ACROSS - Centre of Research Excellence for Advanced Cooperative Systems	EU FP7	2011 2015	3.5 M€	3.5 M€
EC-SAFEMOBIL - Estimation and Control for Safe Wireless High Mobility Cooperative Industrial Systems	EU FP7	2011 2015	3 M€	420 k€

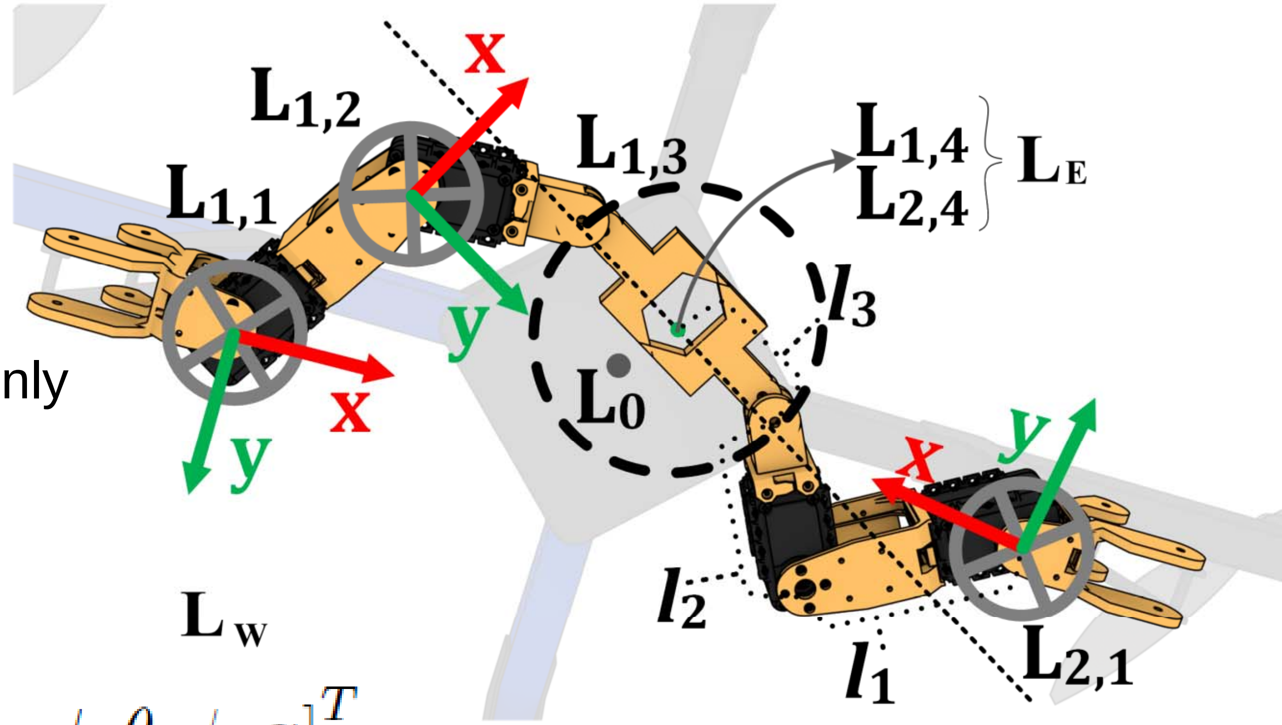
Impedance based force control for aerial robot peg-in-hole insertion tasks

Aerial robot:

- (multi)rotor aerial platform
- multi degree of freedom (dual arm) manipulator
- control the contact force and torque applied to the environment



Kinematic model



dual arm manipulator
=> operates in *x*-*y* plane only

6 + 2*n* dimensions

$$\chi = [x, y, z, \phi, \theta, \psi, \mathbf{q}]^T$$

In practice 4 + 2(*n*-1) dimensions

UAV

one passive joint per arm

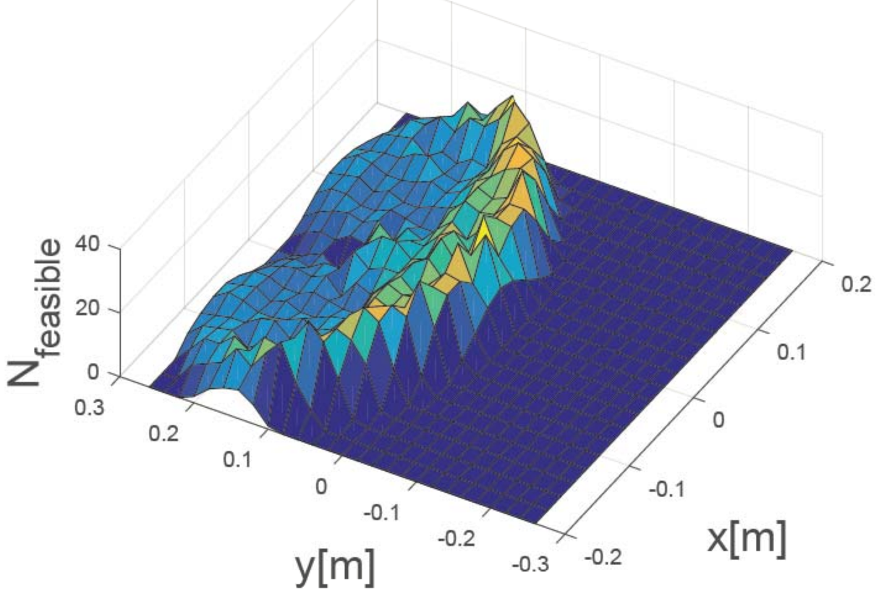
Two serial link manipulators

= > when both arms grab the payload

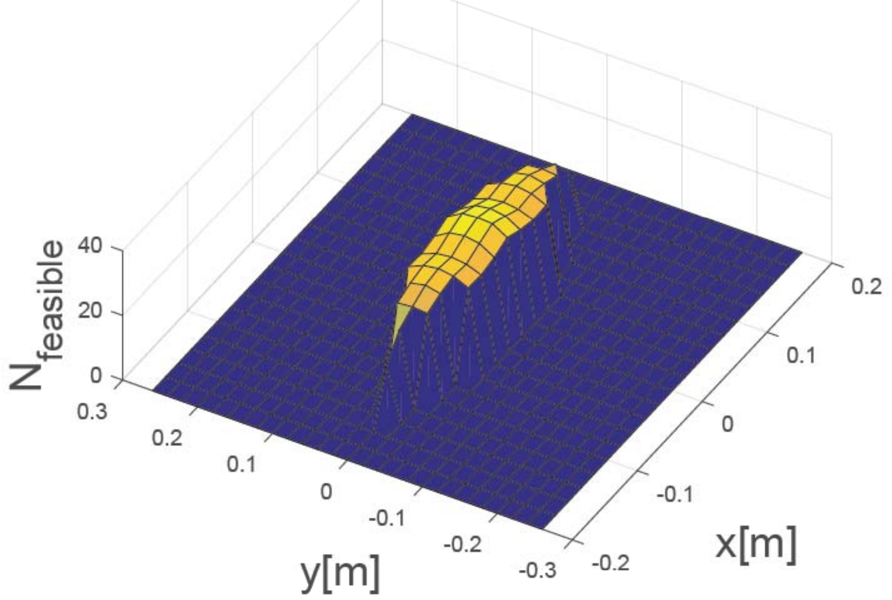
=> one parallel manipulator (payload as common joint)

Requirement: the two passive joints never lose grip on the bolt

Inverse kinematic problem => Solution as position of four active joints

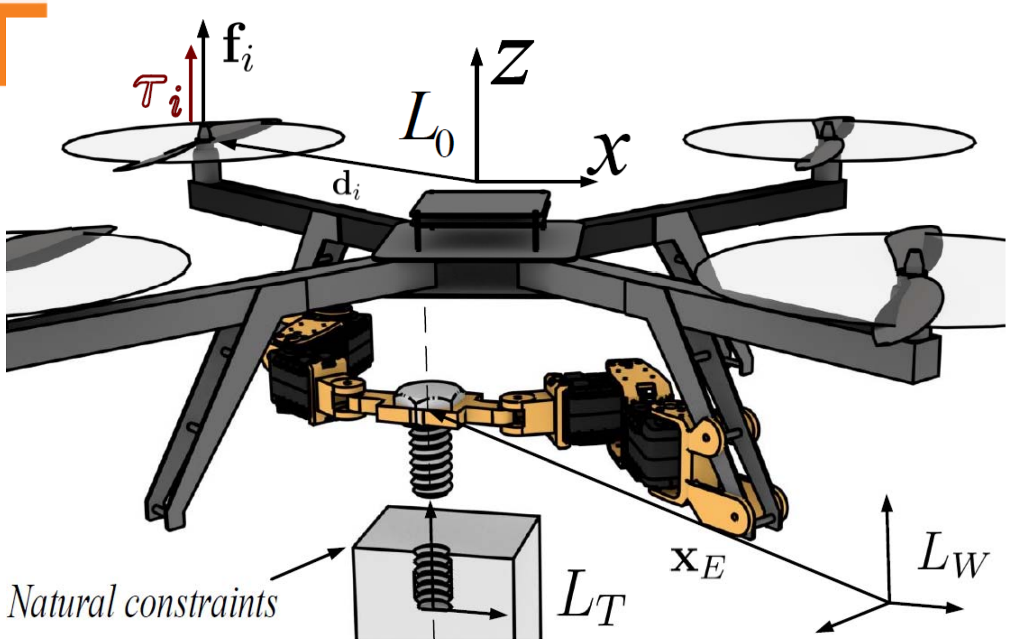


the workspace of the left arm



intersection of workspaces of both arms

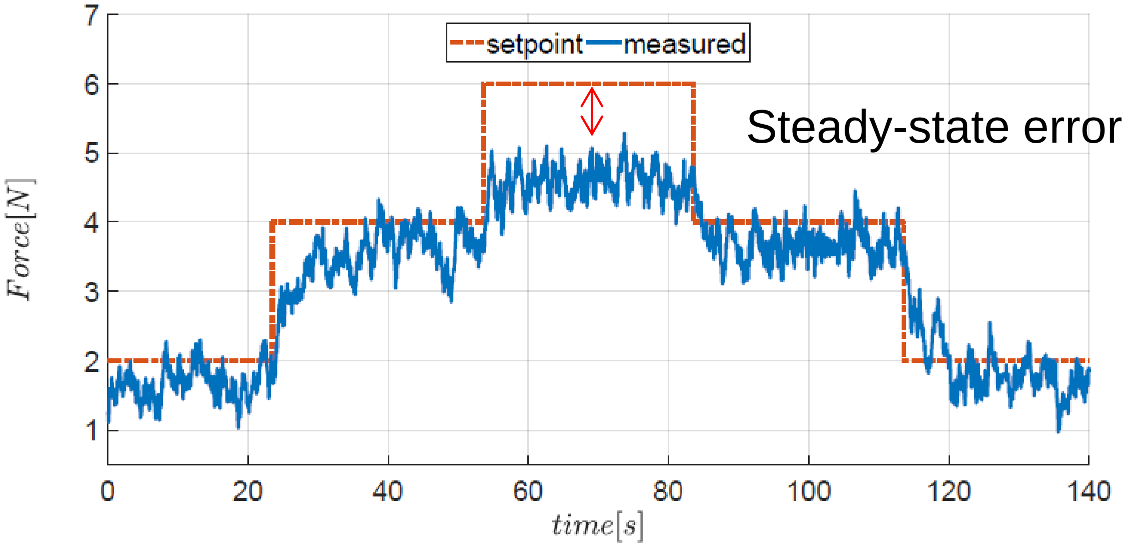
Impedance based force control



$$\mathbf{e} = M\ddot{\mathbf{x}}_c + B\dot{\mathbf{x}}_c + K(\mathbf{x}_c - \mathbf{x}_r)$$

$$e(t) = f_r - f(t) = f_r - k_e(x(t) - x_e)$$

Environment stiffness (*unknown*)

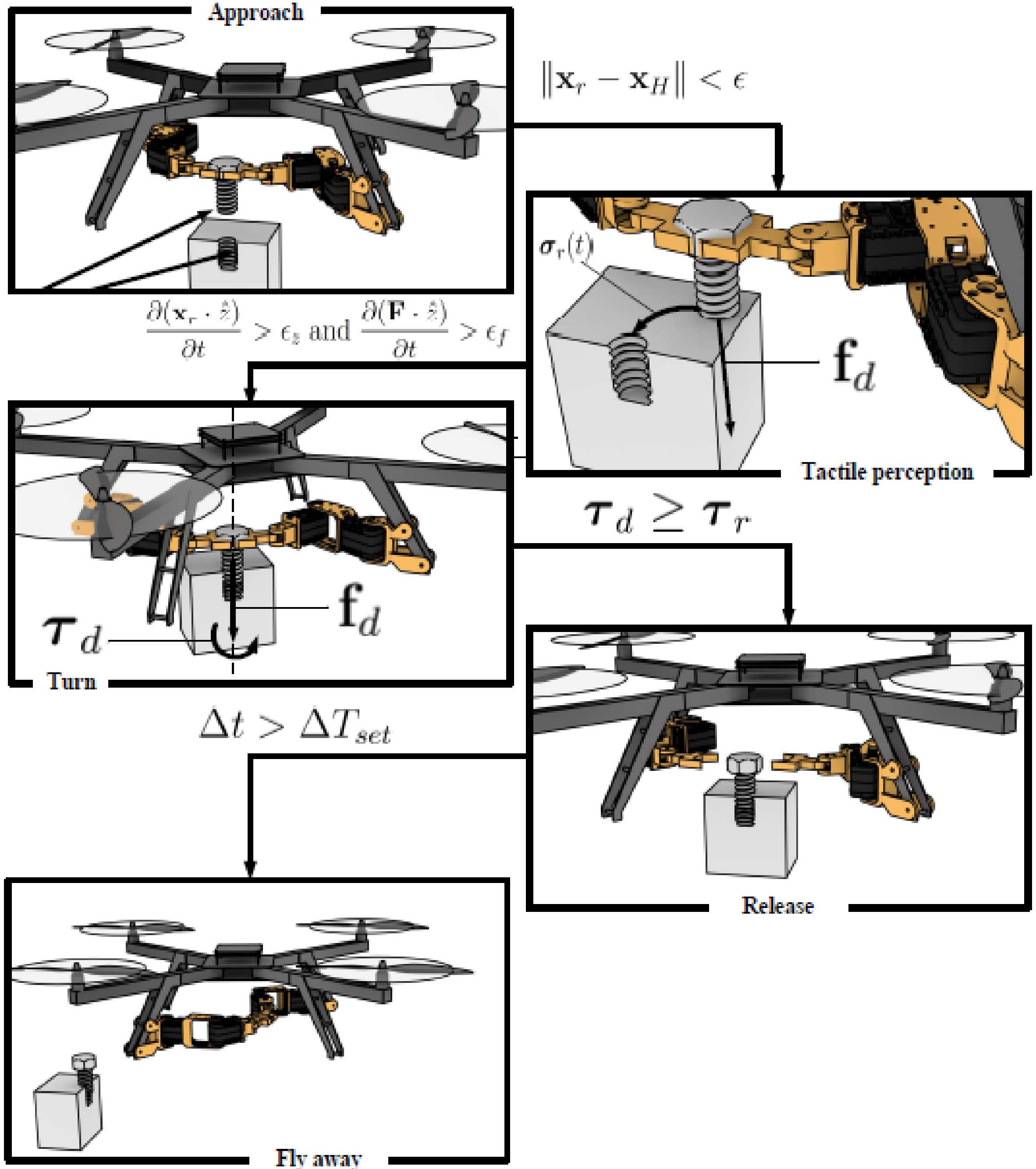


Steady-state error => MRAC

Experimental results

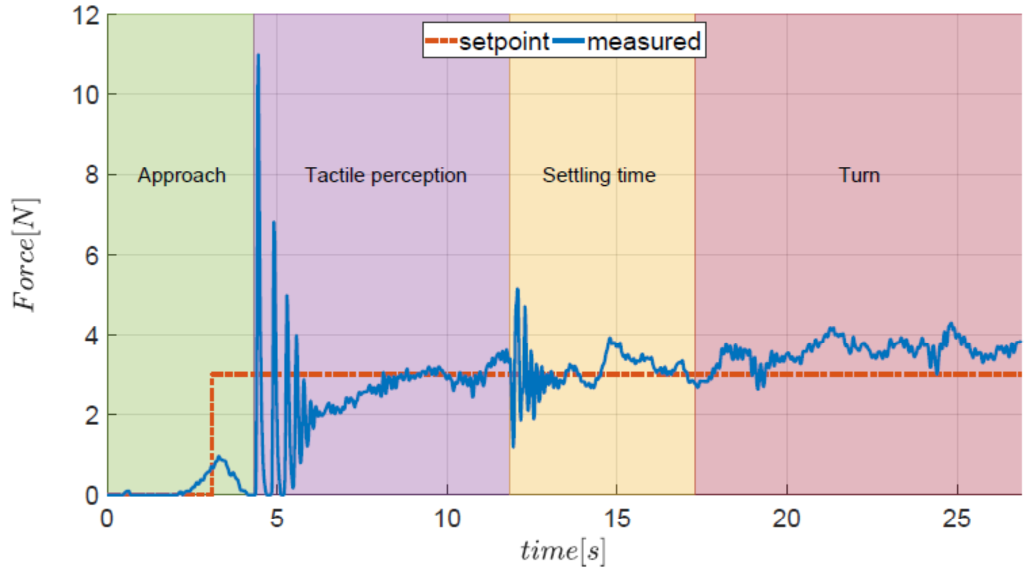
AscTec NEO hexacopter

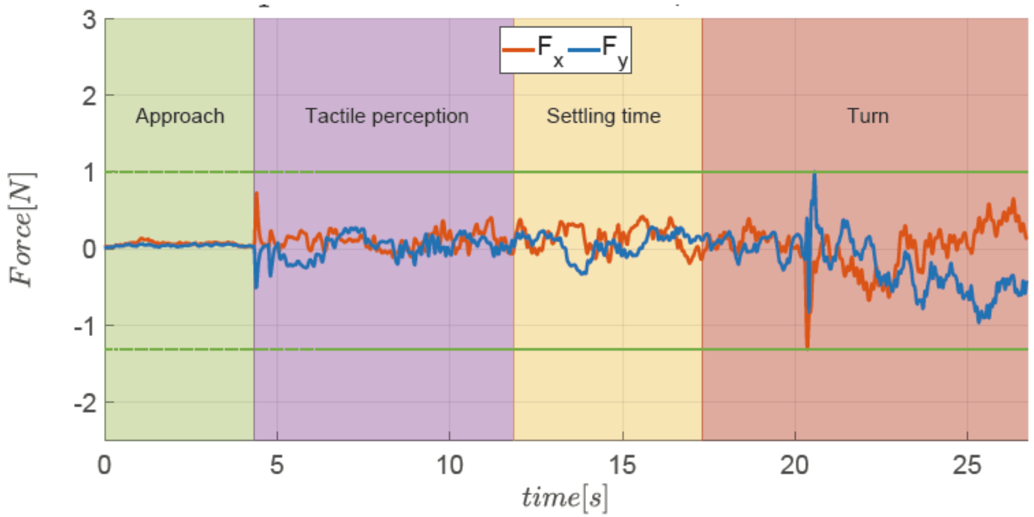
- Intel NUC onboard computer
- on-board camera
- ROS framework.
- 3D printed mechanical parts
- Dynamixel motors

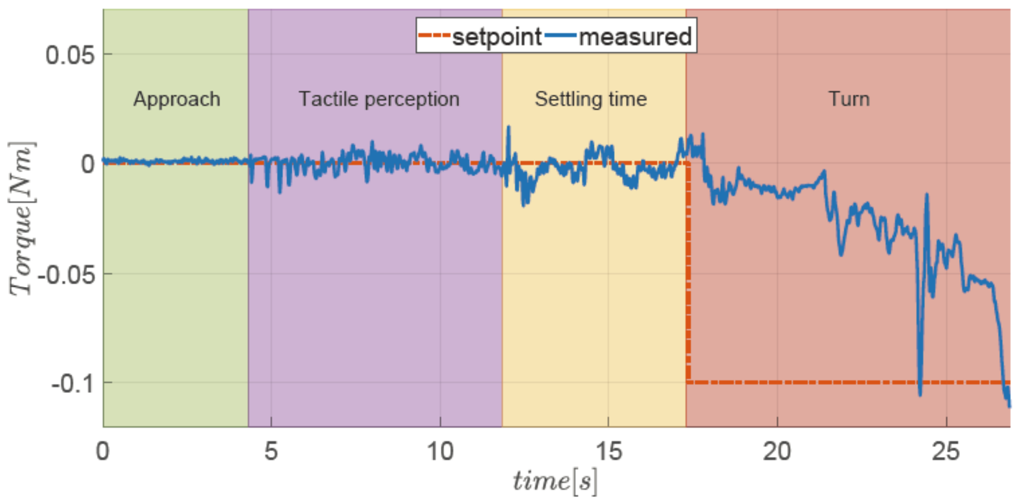


Experimental results

Experimental results

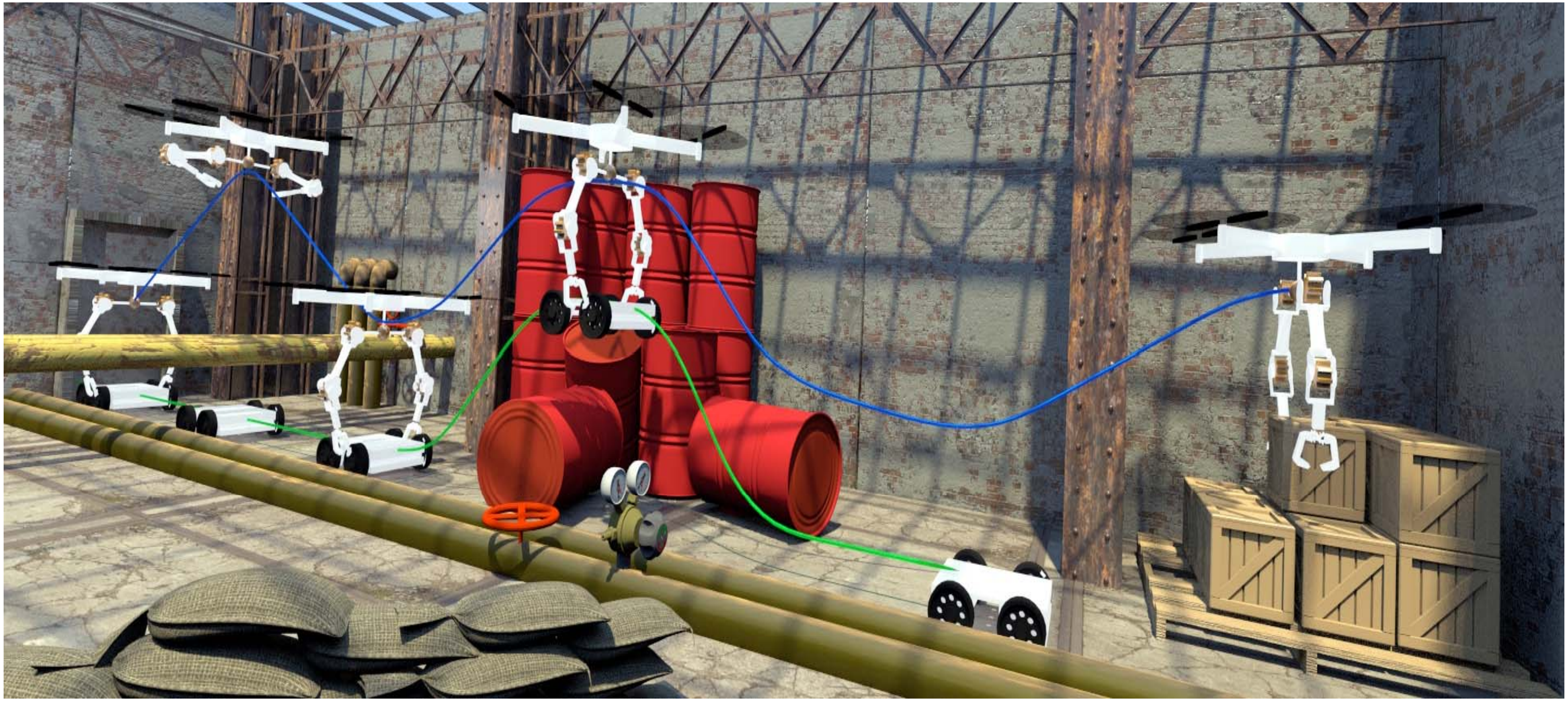






Current work: using one arm to attach UAV to the object and other to apply force/torque

A symbiotic aerial vehicle - ground vehicle robotic team



Requirements

High-level mission planning

⇒ a decentralized hierarchical planning method able to construct and coordinate, ***in real-time***, feasible team plans for a given map of the environment and a given mission,

⇒ feasible missions should be optimized (e.g. min energy)

Low-level control

⇒ a vision-based localization of agents,

⇒ trajectory planning and localization should enable flights in narrow corridors, ***while*** re-planning trajectories ***on-board agents in real-time***.

Mission decomposition and planning

- a mission is comprised of tasks (t_i) and actions (a_i) (TEAMS structure)

$$a_i\,(q_i,\ d_i,\ c_i)$$

quality   duration   cost   => specified by the system designer

$t_i\,(q_i,\ d_i,\ c_i)$ – represents a set of actions (tasks)

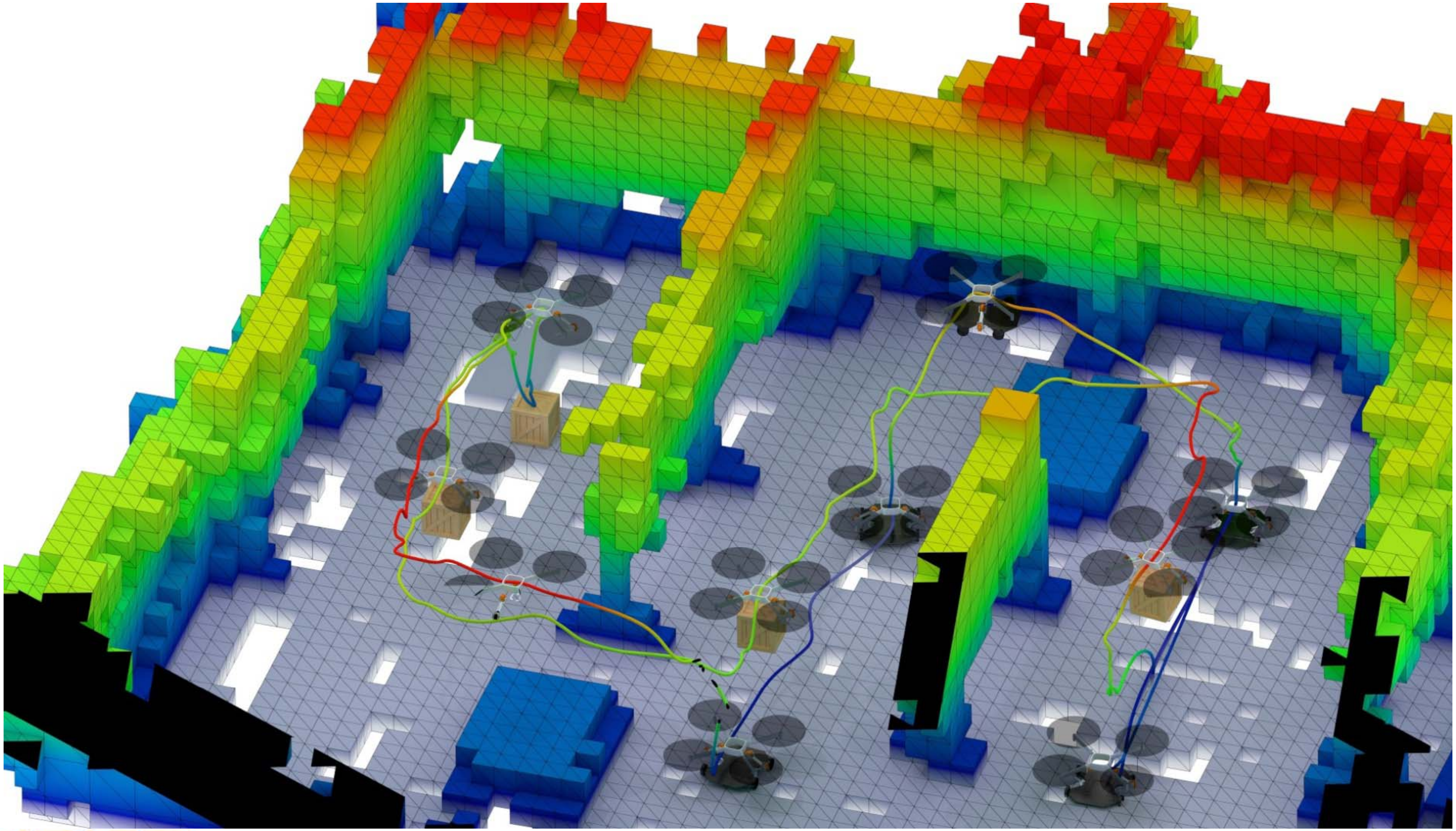
(q_i, d_i) → determined using the quality accumulation function

- precedence constraints on different (actions) tasks

$en(t_a, t_b)$ => t_a should be executed prior to t_b, t_a enables t_b

Mission decomposition and planning

Example: two agents (UAV + UGV) in package transportation mission



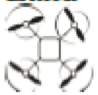
Mission decomposition and planning

Example: two agents (UAV + UGV) in package transportation mission

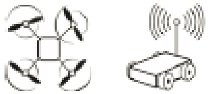
Actions

Takeoff

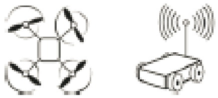
Land



Move to desired position



Hold position

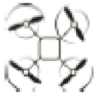


Grab L-UGV

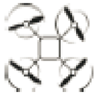
Release L-UGV

Grab parcel

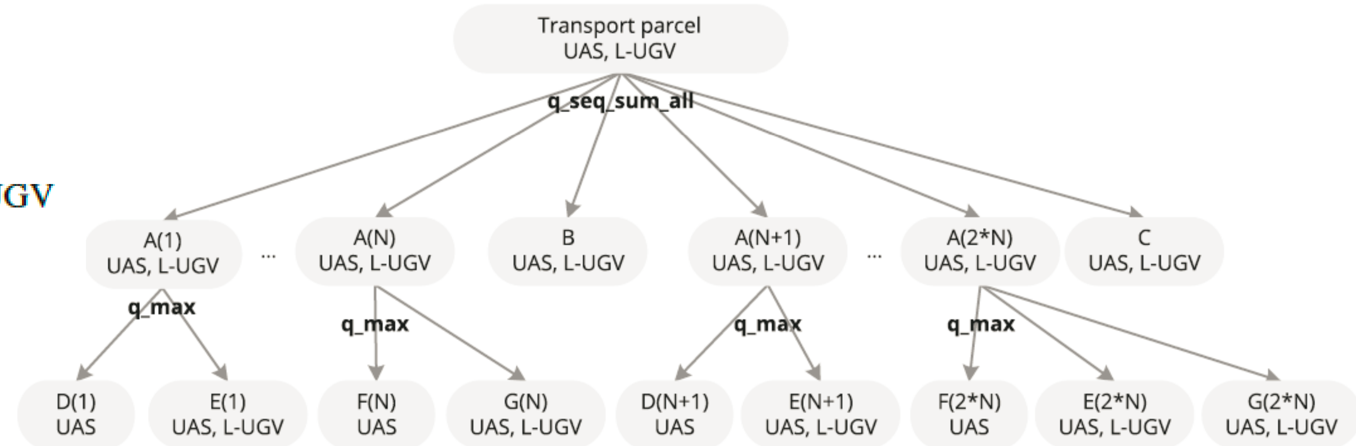
Release parcel



Land on the L-UGV with the parcel



Mission decomposition in tasks
(case with *N* obstacles)



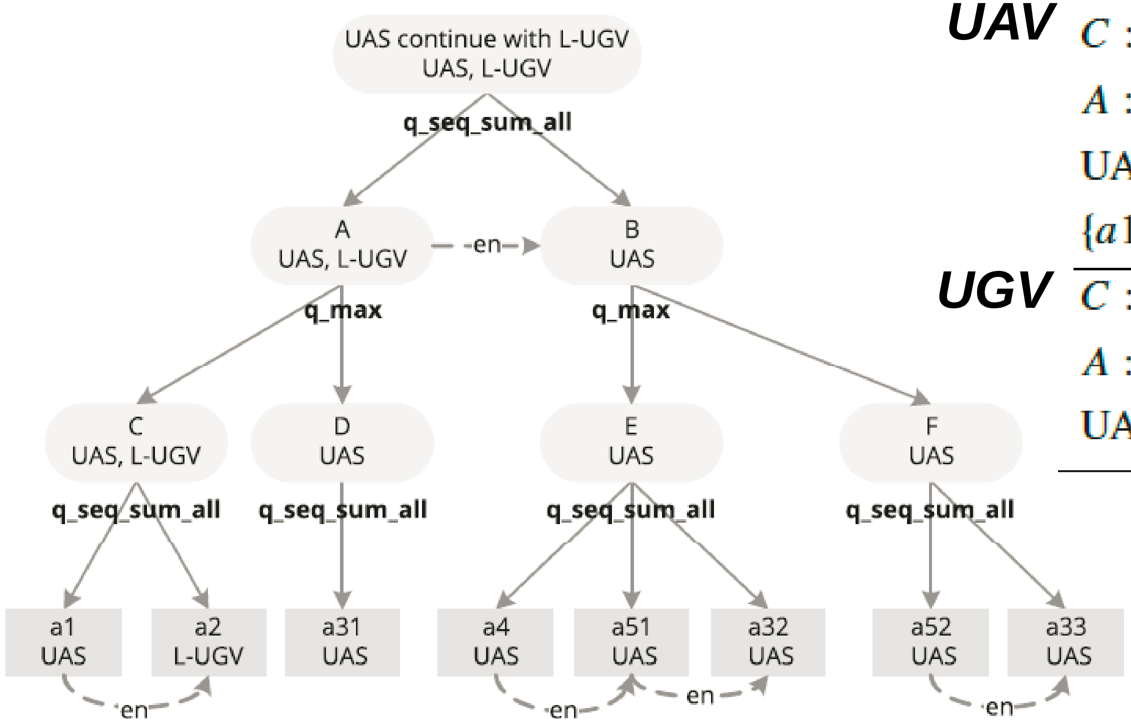
A = Cross the obstacle
B = Pick up parcel
C = Deliver parcel

D = UAS go alone
E = UAS go with L-UGV
F = UAS continue alone
G = UAS continue with L-UGV

Mission decomposition and planning

Example: two agents (UAV + UGV) in package transportation mission

Task decomposition



A = UAS and L-UGV go to the obstacle
B = Cross the obstacle
C = L-UGV drive UAS to the obstacle
D = UAS fly L-UGV to the obstacle
E = UAS cross alone
F = UAS cross with L-UGV

a1 = UAS land with L-UGV
a2 = L-UGV go to position
a3x = UAS go to position
a4 = Release
A5x = Takeoff

	Task alternatives
UAV	$C : \{a1, a2\}$, $D : \{a31\}$, $E : \{a4, a51, a32\}$, $F : \{a52, a33\}$
	$A : \{a1, a2\}, \{a31\}$, $B : \{a4, a51, a32\}, \{a52, a33\}$
	UAS continue with L-UGV : $\{a1, a2, a4, a51, a32\}$
	$\{a1, a2, a52, a33\}, \{a31, a4, a51, a32\}, \{a31, a52, a33\}$
UGV	$C : \{a1, a2\}$
	$A : \{a1, a2\}, \{D\}$
	UAS continue with L-UGV : $\{a1, a2, B\}, \{D, B\}$

Example: two agents (UAV + UGV) in package transportation mission

Mission cost (*c*) = > Energy budget

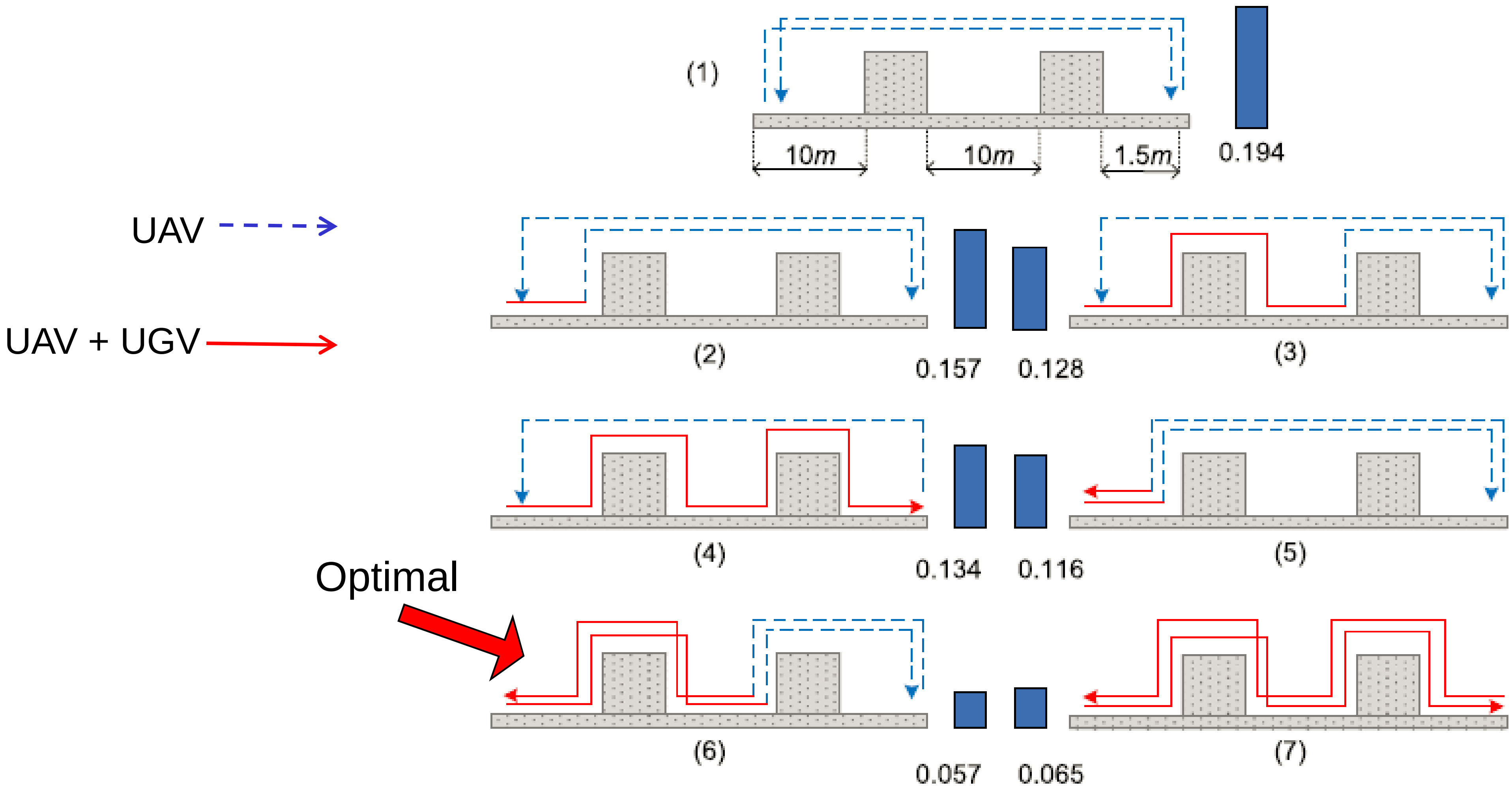
		C1	C2	C3	C4
UAS	2.7 kg	X	X	X	X
L-UGV	0.4 kg		X		X
parcel	0.1 kg			X	X
		2.7 kg	3.1 kg	2.8 kg	3.2 kg

Takeoff (A1), Land (A2),
Move to desired position — Fly (A3), Drive (A4)

	C1	C2	C3	C4
A1	579 W	711 W	616 W	731 W
A2	566 W	696 W	602 W	729 W
A3	570 W	701 W	606 W	744 W
A4	N/A	N/A	3.3 W	3.3 W

Example: two agents (UAV + UGV) in package transportation mission

Feasible solutions



Experimental results

Thank you.