Sensor Delivery in Forests with Aerial Robots: New Paradigms for Environmental Monitoring

Salua Hamaza & Andre Farinha | Mirko Kovac
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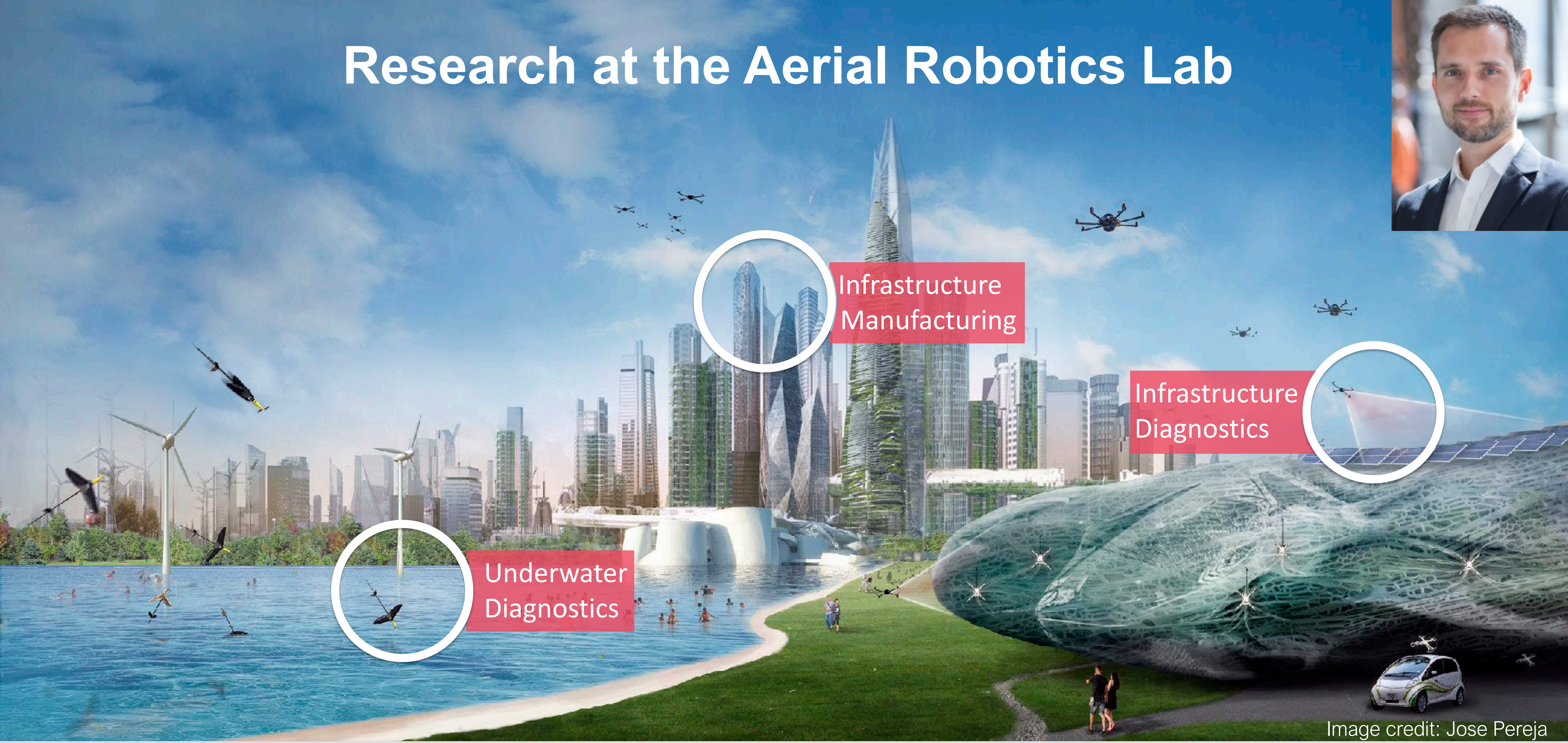
Research at the Aerial Robotics Lab



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Sensor Delivery in Forests with Aerial Robots

Ecological Monitoring

Climate Change

Forest Fires Prevention

Questions :

How does forest structure and sensors requirements influence the design of delivery methods?

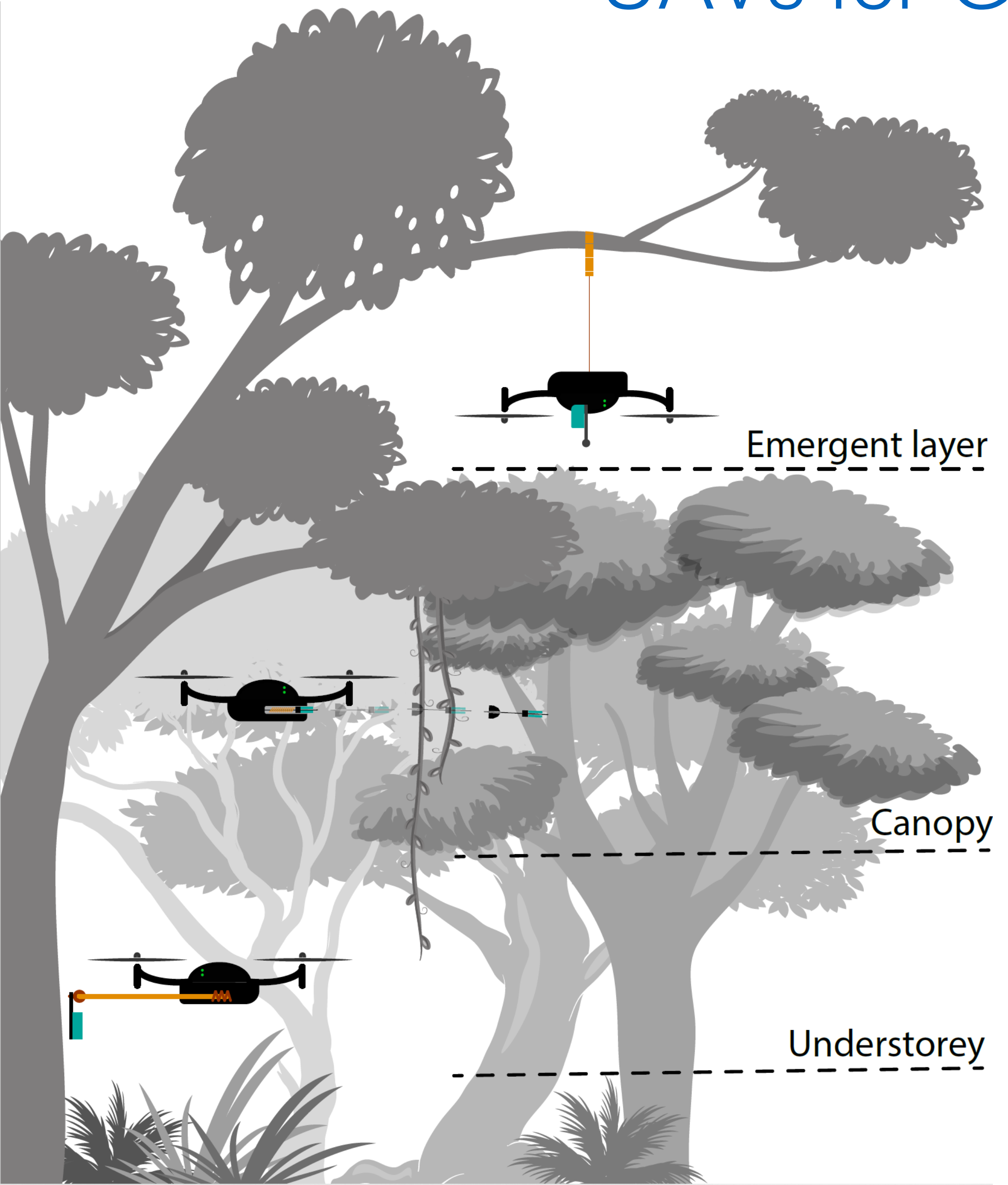
What level of robot–environment interaction is required to precisely deploy sensors?

Which control and perception frameworks are appropriate for sensor placement in forests?

UAVs for Geospatial Mapping

- ➢ Spatially dense, yet sparse time series
- ➢ Not ideal for monitoring long-term changes
- ➢ Cluttered environments, challenging for any mobile robot

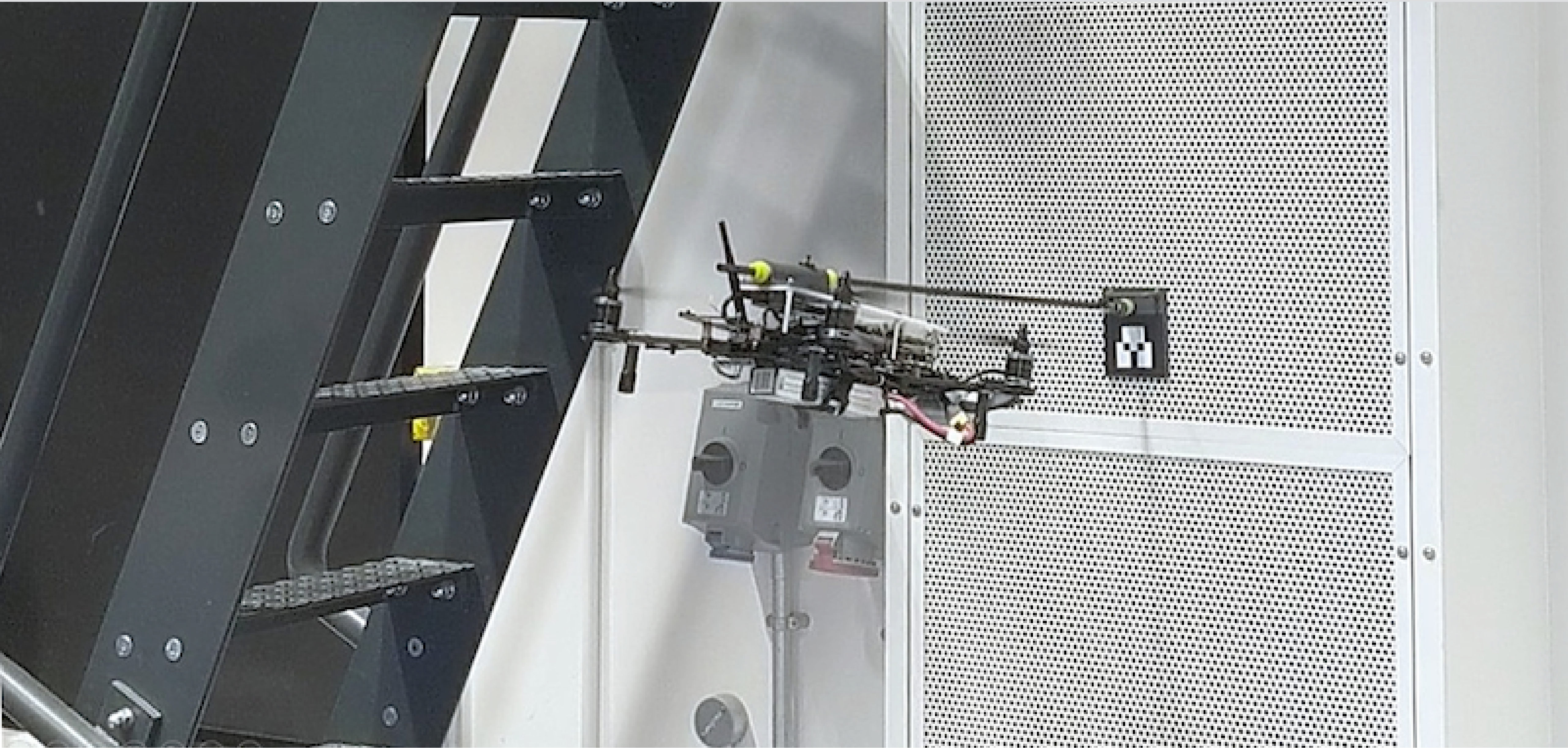
UAVs for Geospatial Mapping



- ➢ Spatially dense, yet sparse time series
- ➢ Not ideal for monitoring long-term changes
- ➢ Cluttered environments, challenging for any mobile robot

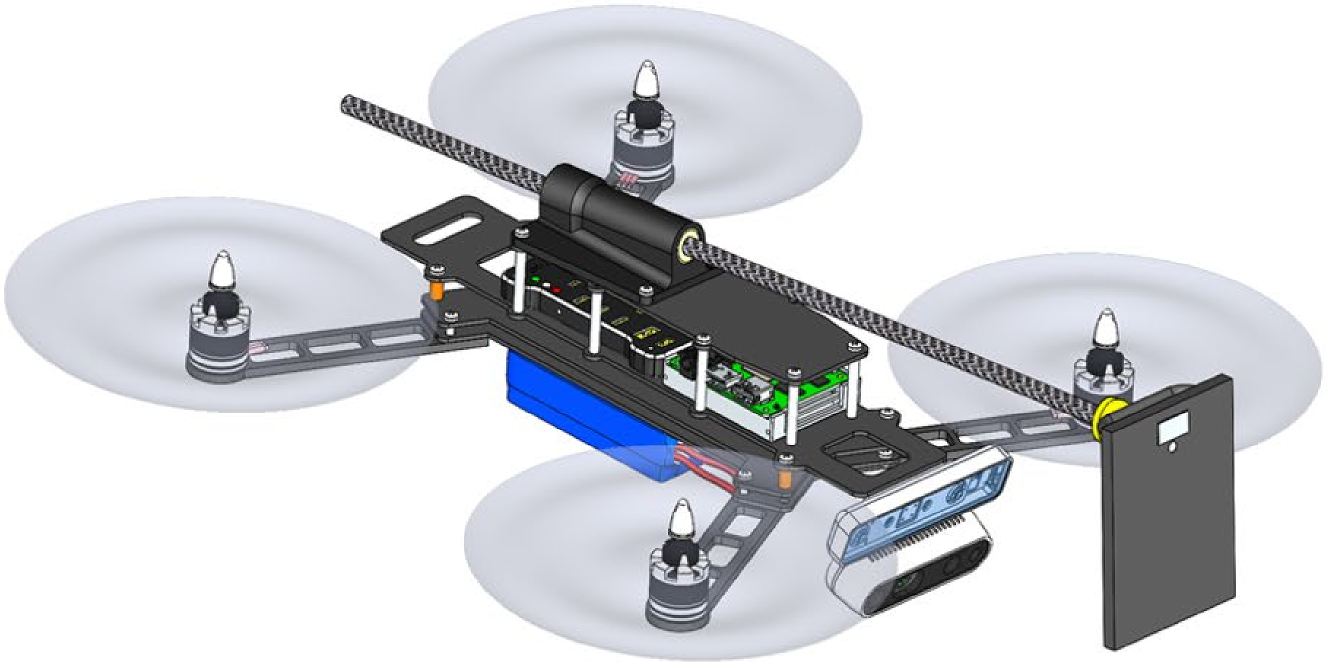
sensor deployment with UAVs
can reduce the time and financial effort to
acquire datasets with appropriate
spatio-temporal resolution

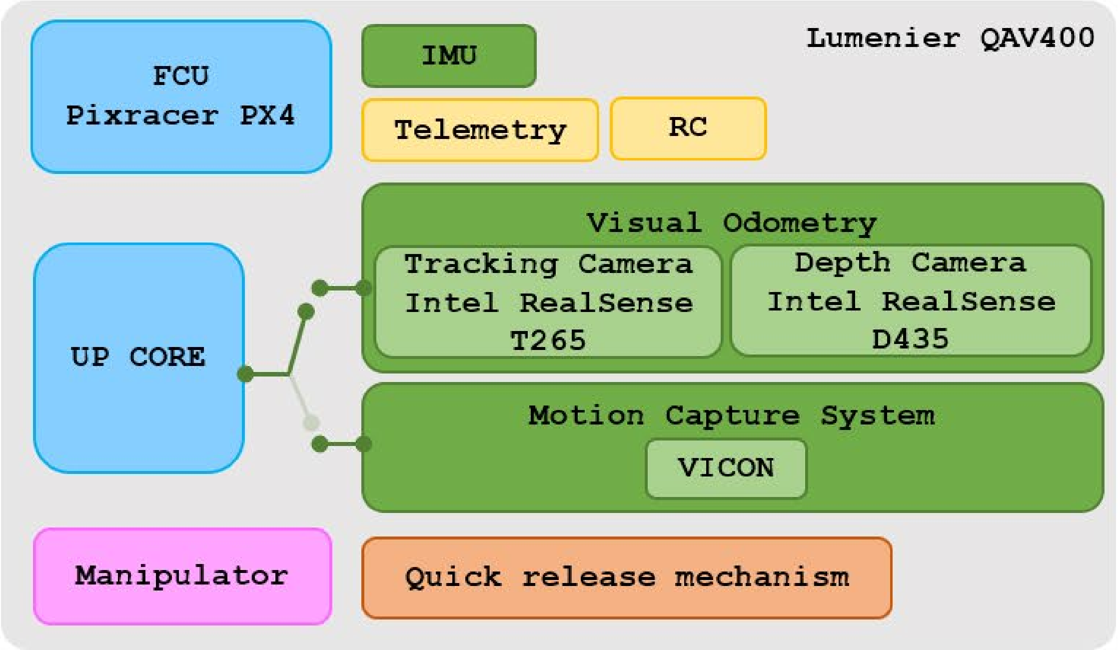
Direct Sensor Placement



Aerial Manipulator

Hardware Architecture

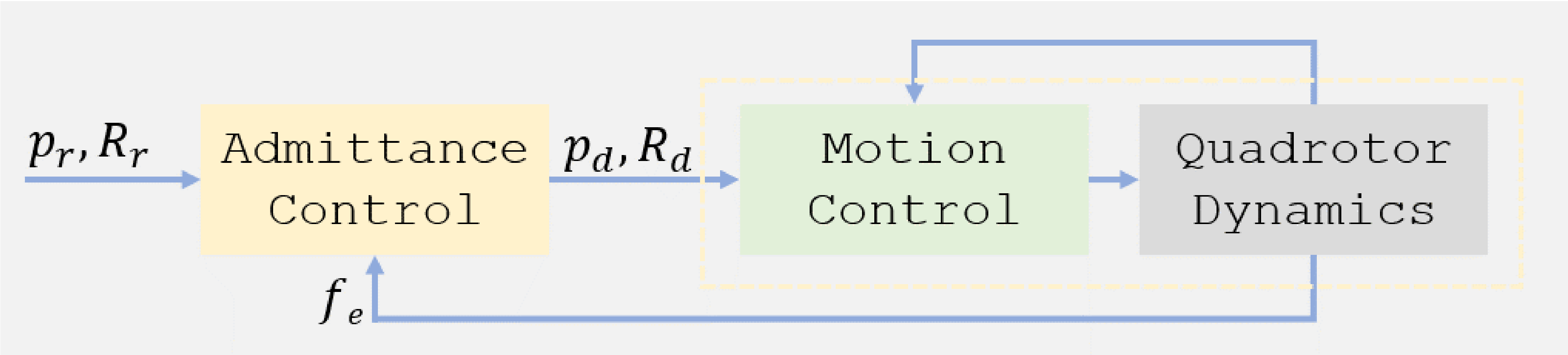




- ➢ Small-sized quadcopter <1kg
- ➢ Passive mechanism
- ➢ Compliant gripper with magnetic attachment

Admittance Controller

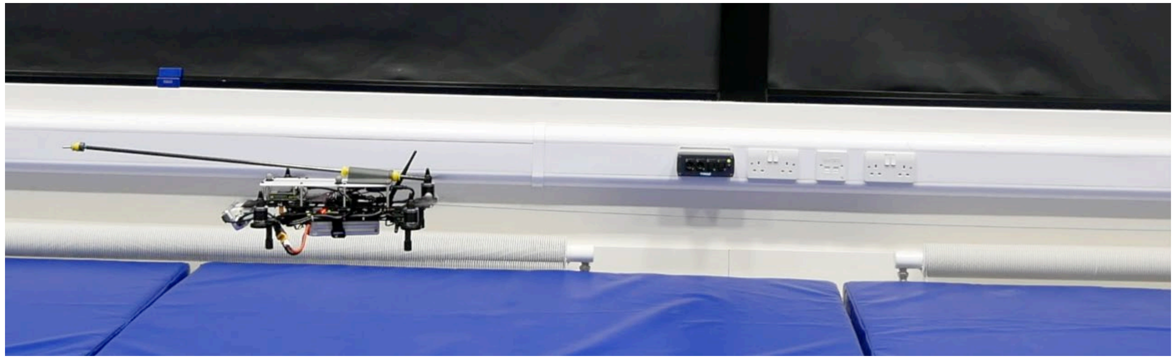
Control strategy

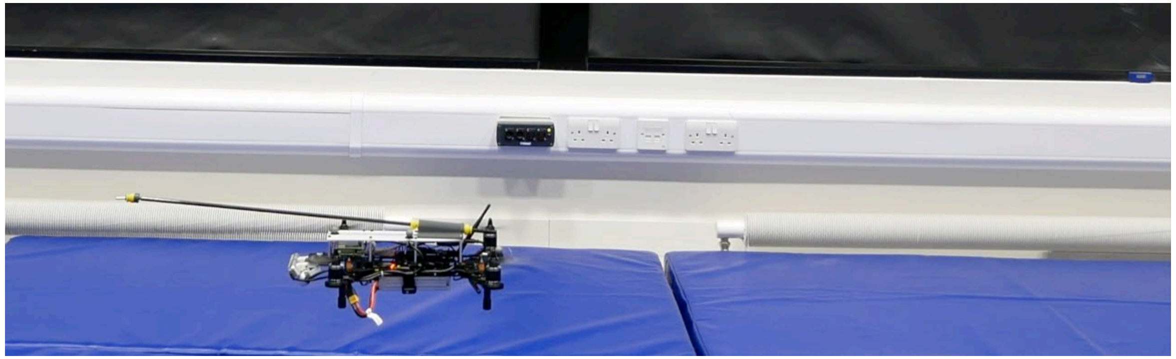


$$m_d \ddot{e}_r + b_d \dot{e}_r + k_d e_r = f_e$$

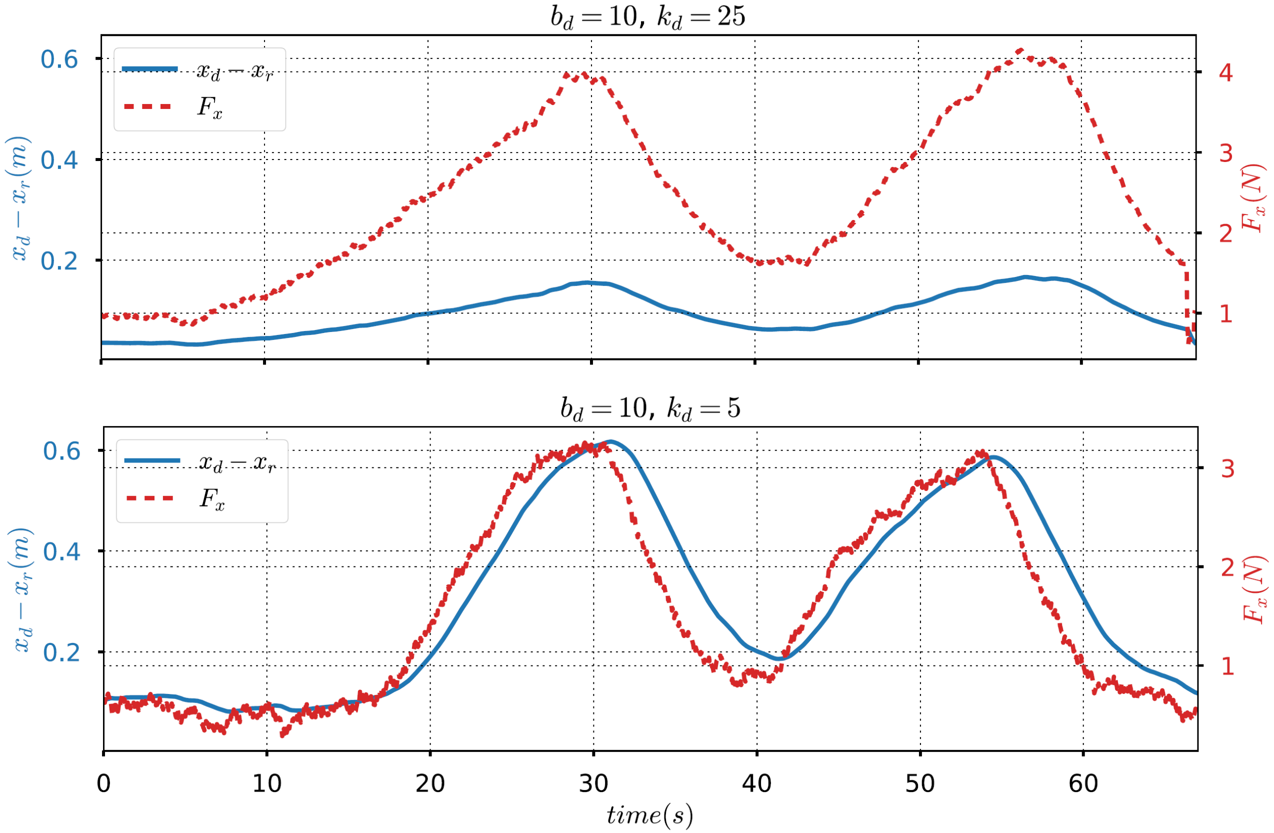
Admittance Controller

Response under unknown external force





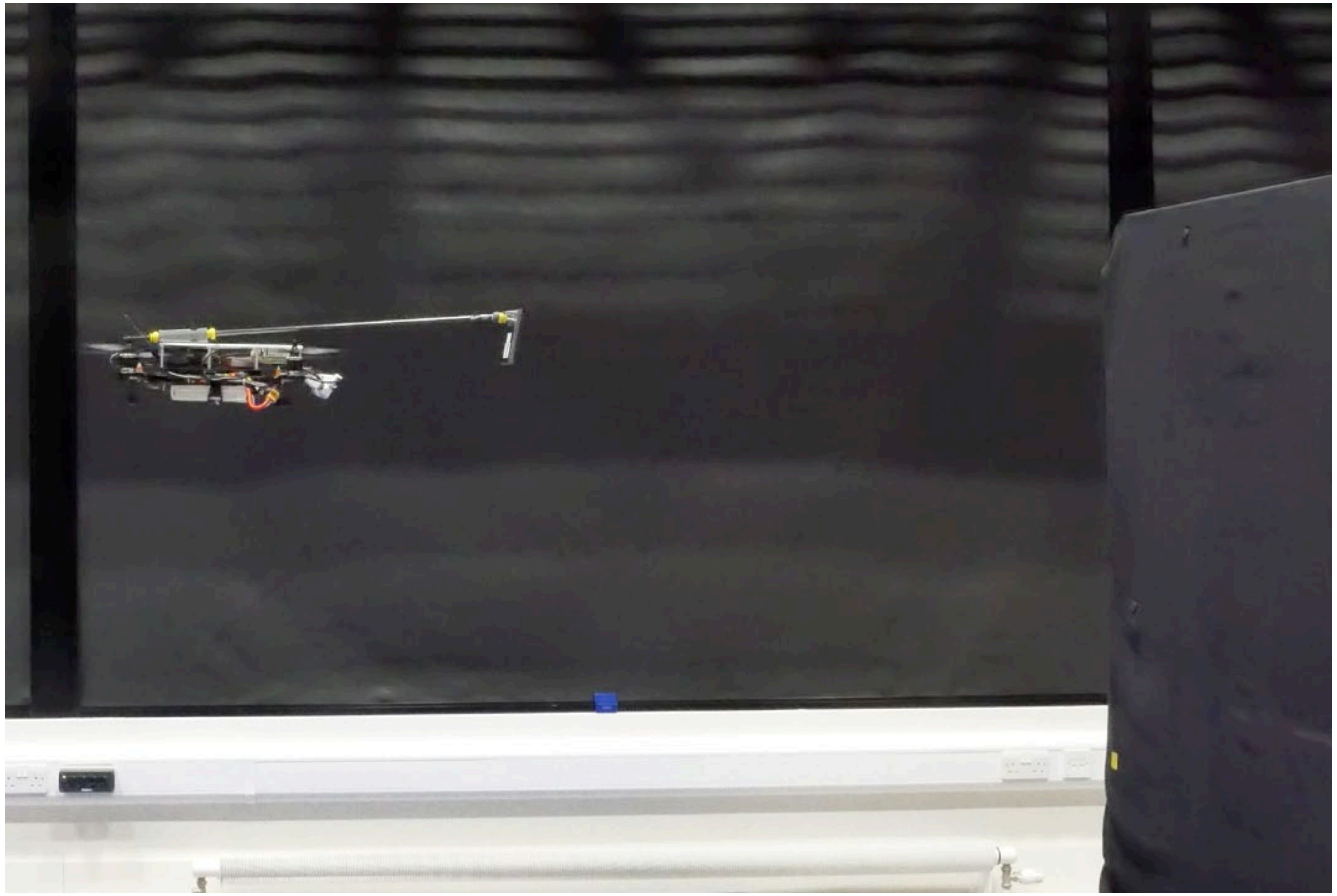
manually pulling back the aerial robot with a cable



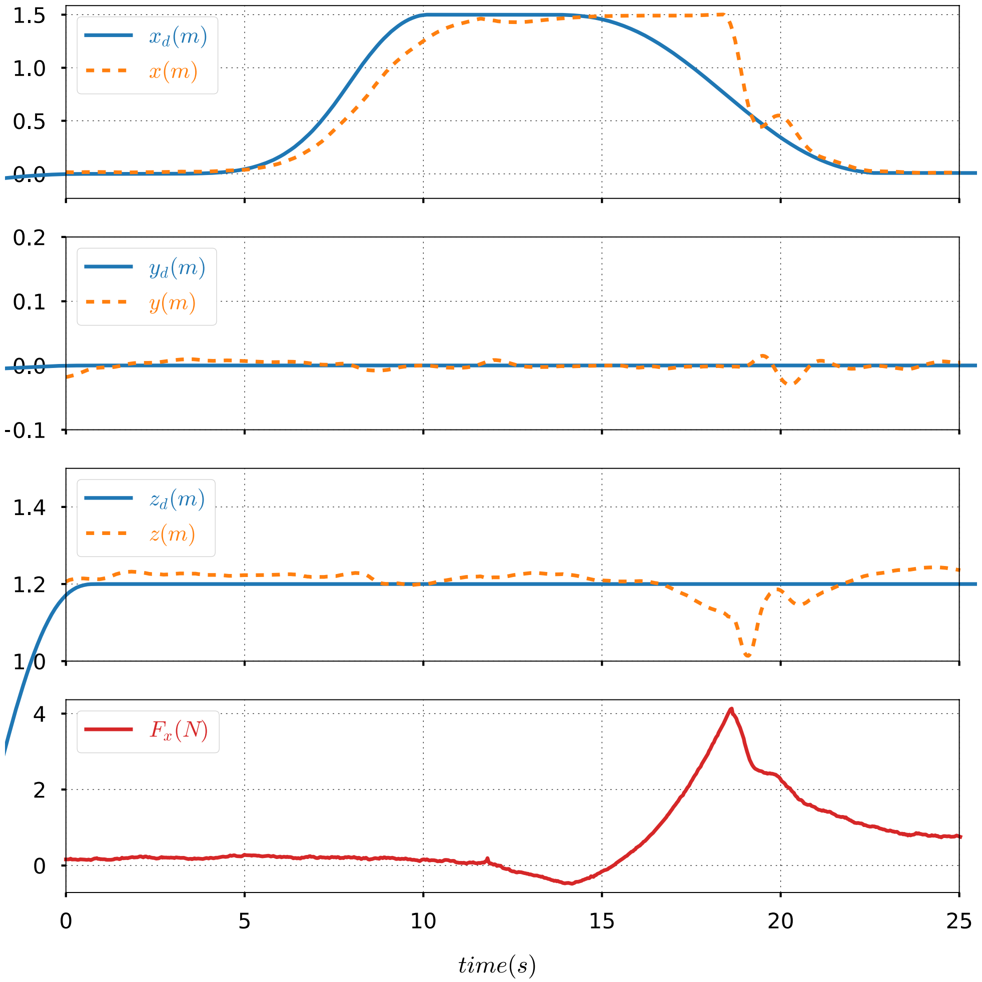
force estimation and response

Autonomous Placement

Onboard Sensing and Computing

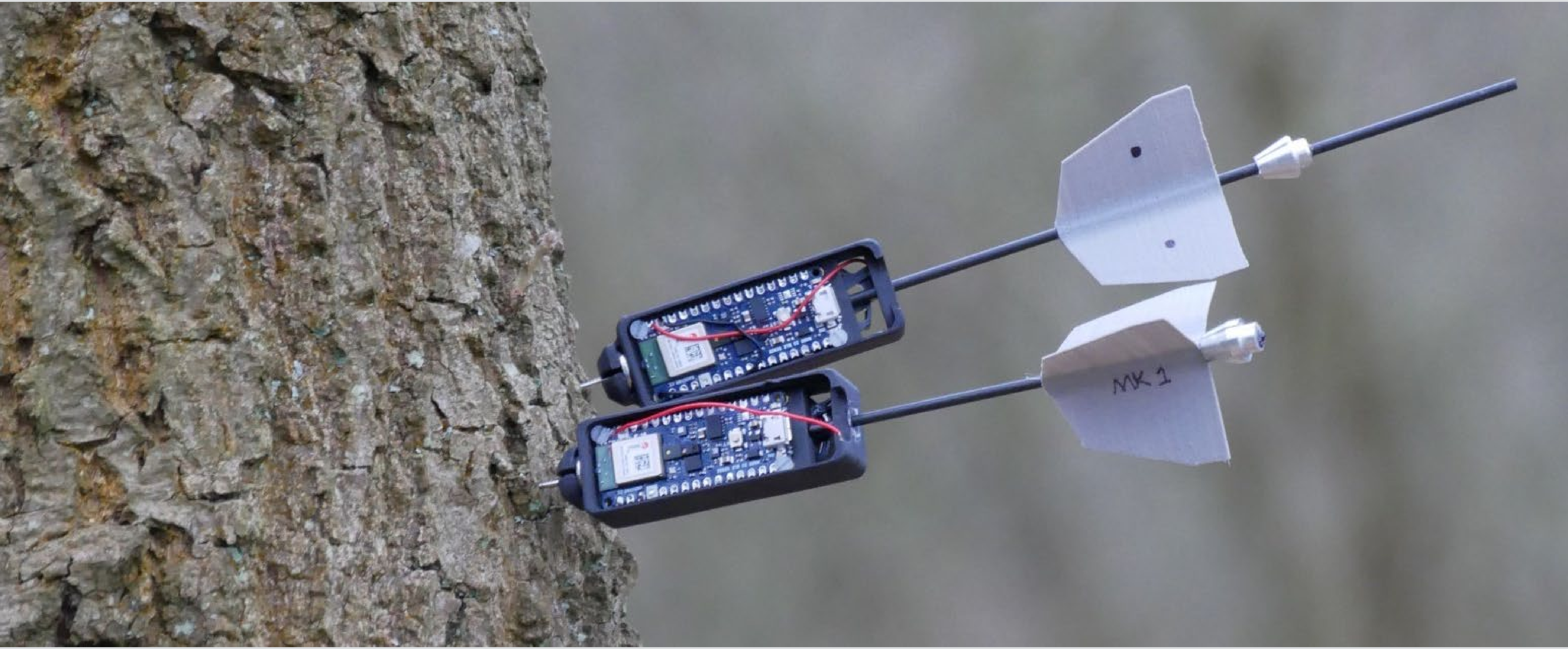


sensor placement sequence



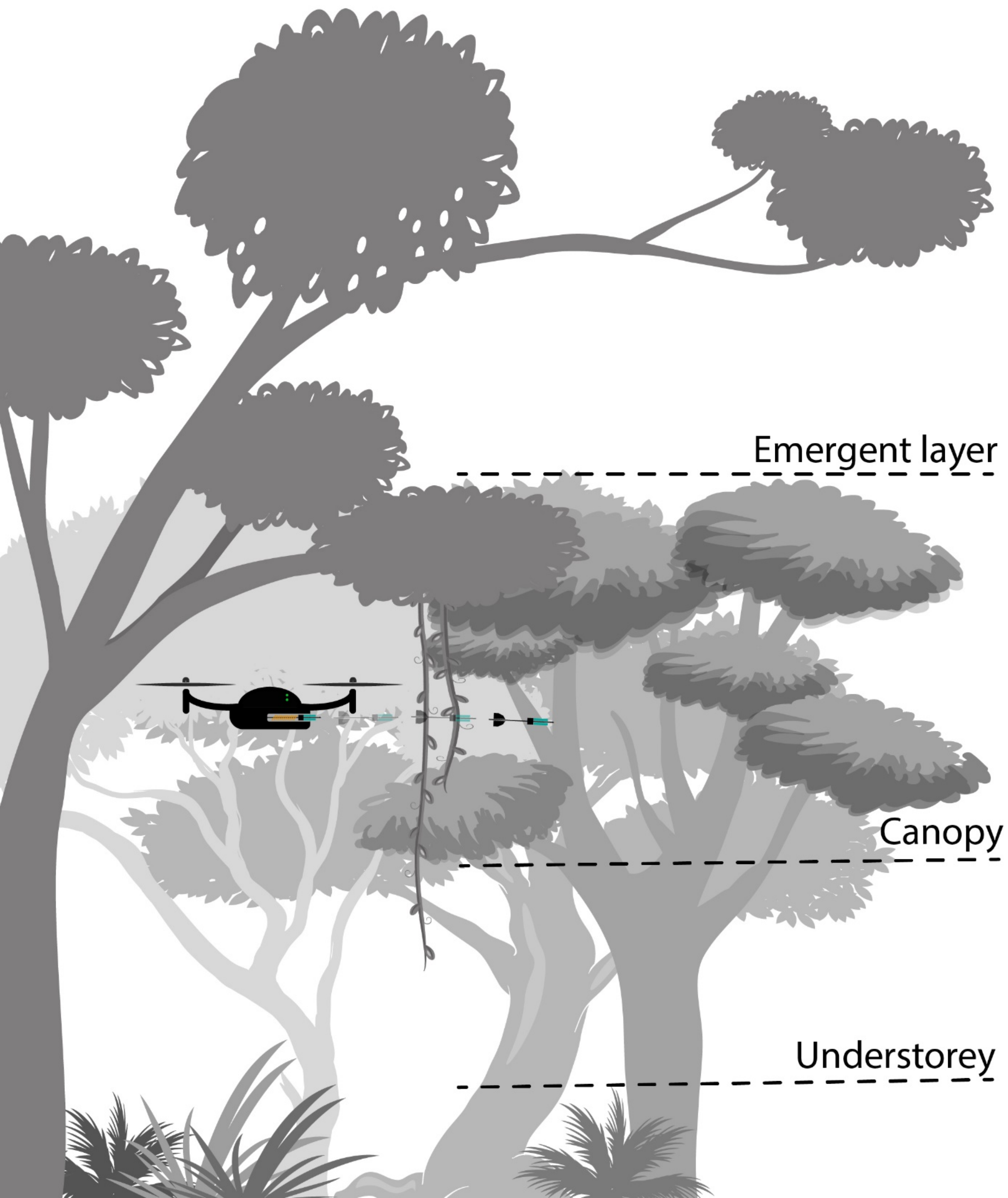
trajectory tracking and force estimation

Sensor Launching



A. Farinha, R. Zufferey, P. Zheng, S. F. Armanini and M. Kovac, "Unmanned Aerial Sensor Placement for Cluttered Environments," in IEEE Robotics and Automation Letters, vol. 5, no. 4, pp. 6623-6630]

Sensor Launching

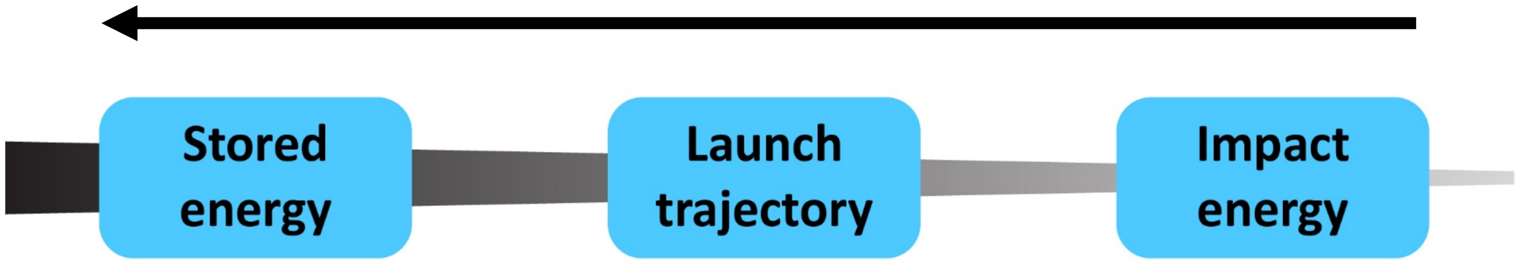


Sensor launching strengths

- Gap means safety
- Little added payload
- Accuracy

Conceptual Design

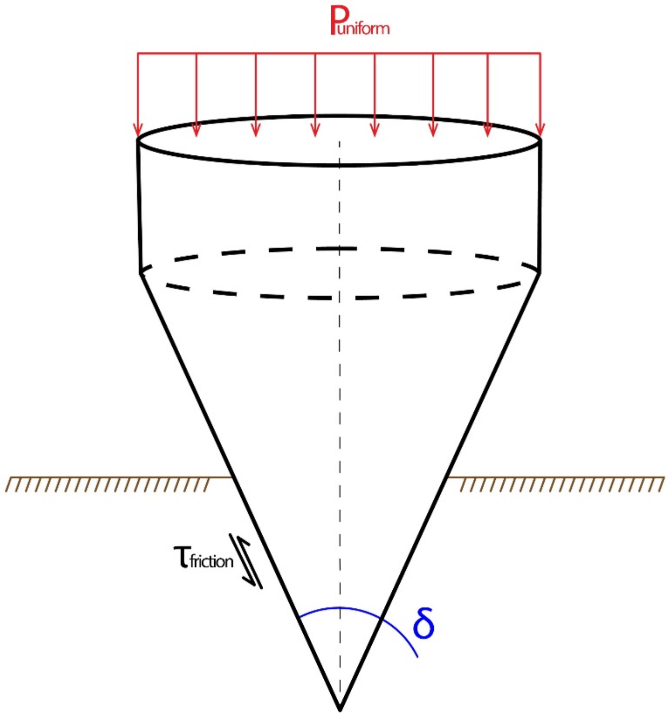
Design, Projectile Trajectory and Energy Dissipation



Conceptual Design

Design, Projectile Trajectory and Energy Dissipation

1. Impact



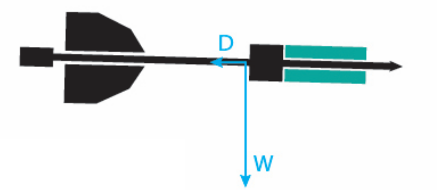
$$U_{pen} = \int_{\delta} F_{ind} + F_{fric} d\delta$$

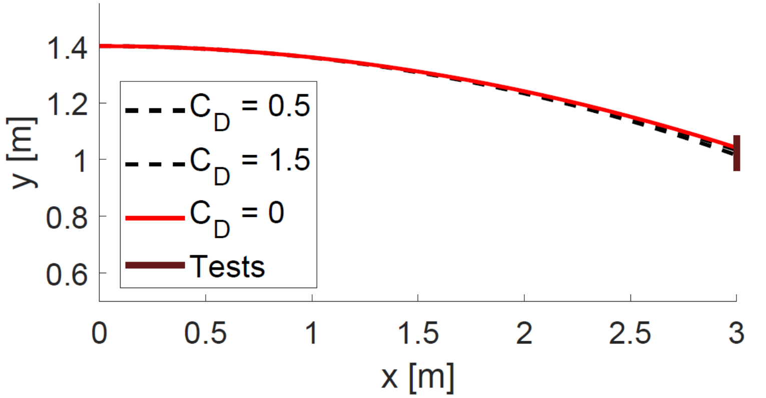
$$F_{ind} = 3\sigma_y \pi r^2(\delta)$$

$$F_{fric} = \frac{\sigma_y}{2} 2\pi R\delta$$

	Red Pine	Birch	Chestnut	Oak	Willow
Wood	7.25 J	8.76 J	8.31 J	12.68 J	7.10 J
Bark	0.87 J	1.05 J	1.00 J	1.53 J	0.85 J

2. Trajectory



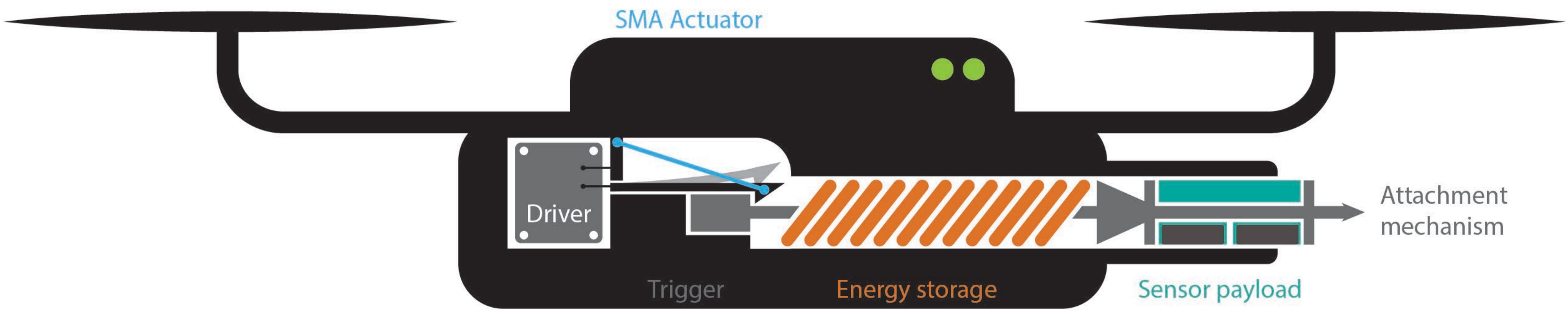


3. Mechanical energy

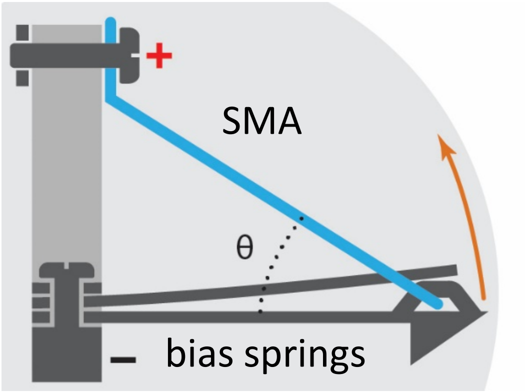
- ➢ Buckling rods
- ➢ Elastomers
- ➢ Linear springs

Aerial Launcher

Hardware Architecture



System Integration



- SMA actuation
- High specific actuation force
- Predictable actuation time

- Phase fraction equation

$$R(T,\sigma)=\frac{1}{1+exp(C_K\cdot(T-c\cdot\sigma-T_m))}$$

$$T_m=\frac{A_s+A_f}{2}$$

$$C_K=\frac{4.4}{A_f-A_s}$$

- Heat exchange equation

$$\rho V\cdot\frac{dT}{dt}=S_J-\ddot{q}_{conv}-\ddot{q}_{cnt}$$

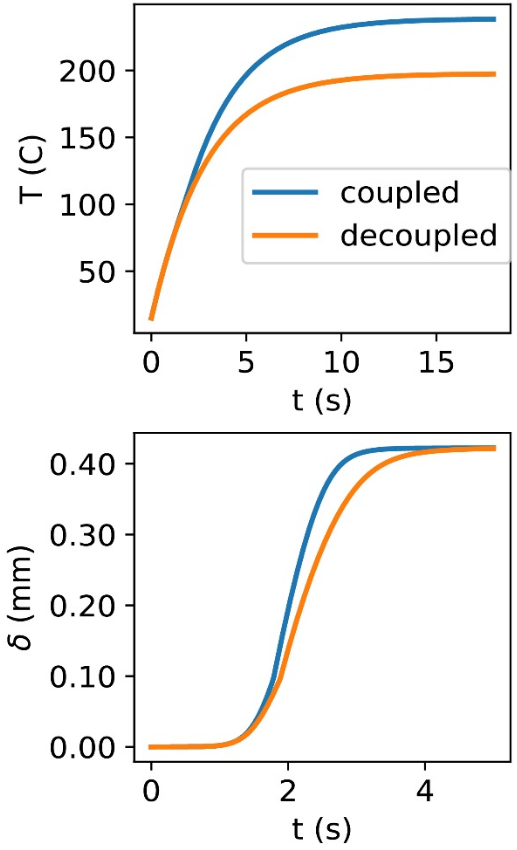
- Bias spring equation

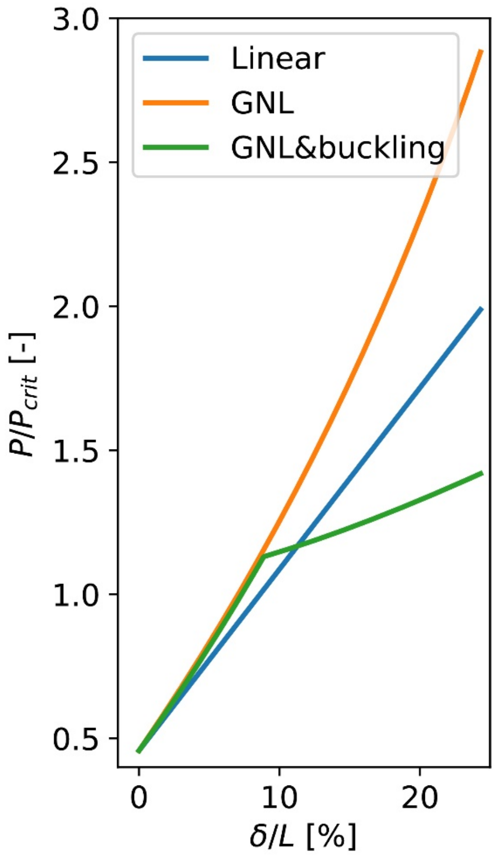
$$F_y(\theta)=\frac{3EI}{L^3}\delta_y$$

$$P_{crit}=\frac{2\pi^2 EI}{L^2}$$

- Material constitutive law

$$\epsilon=(1-R)\frac{\sigma}{E_A}+R(\frac{\sigma}{E_R}+\alpha(\sigma_2-\sigma1)+\epsilon_r)$$





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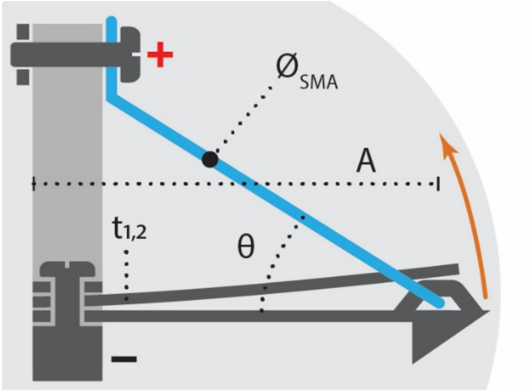

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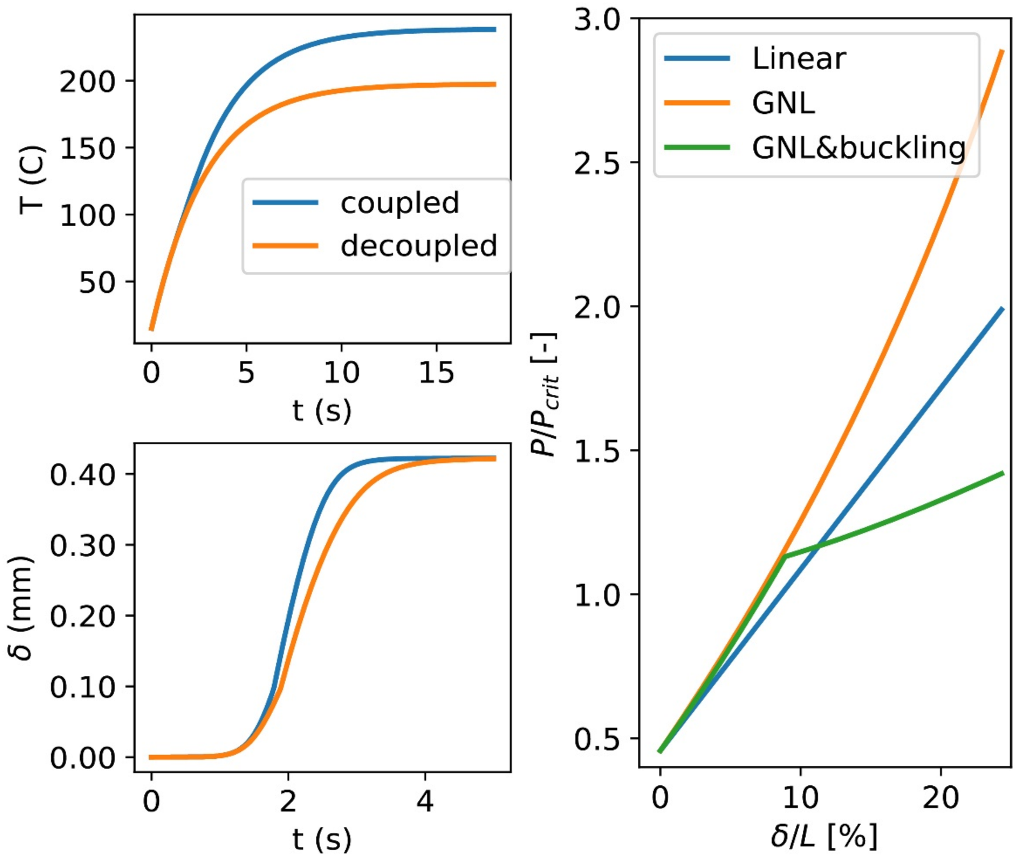

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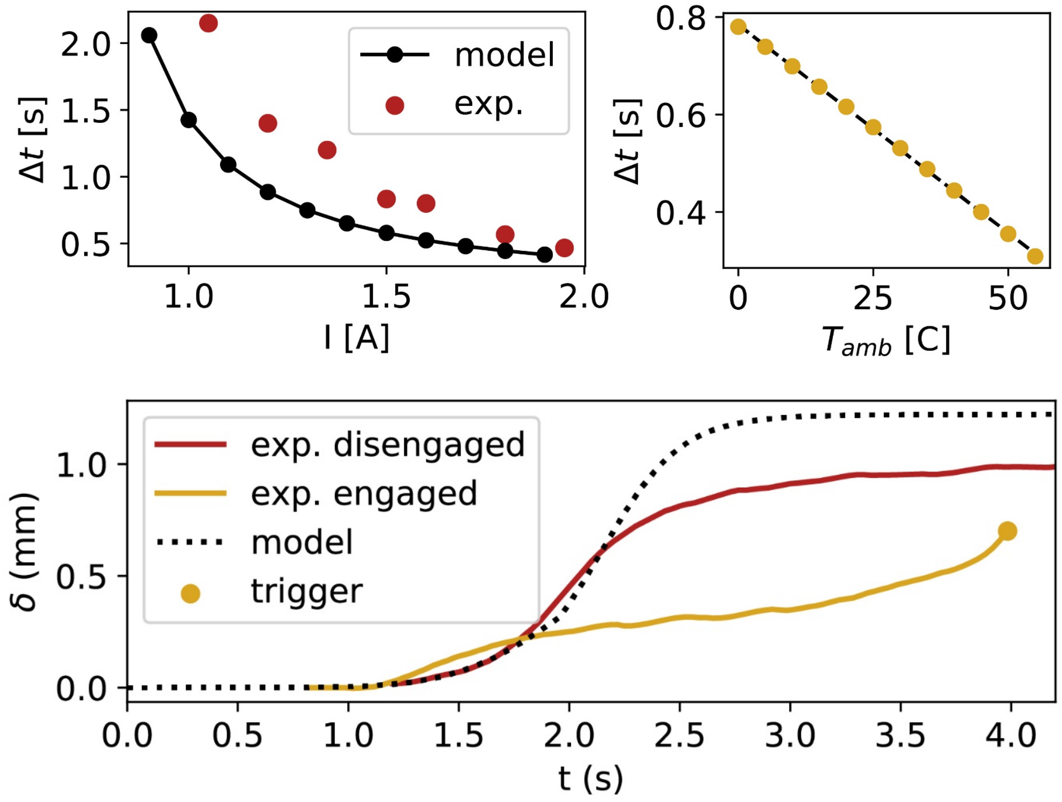
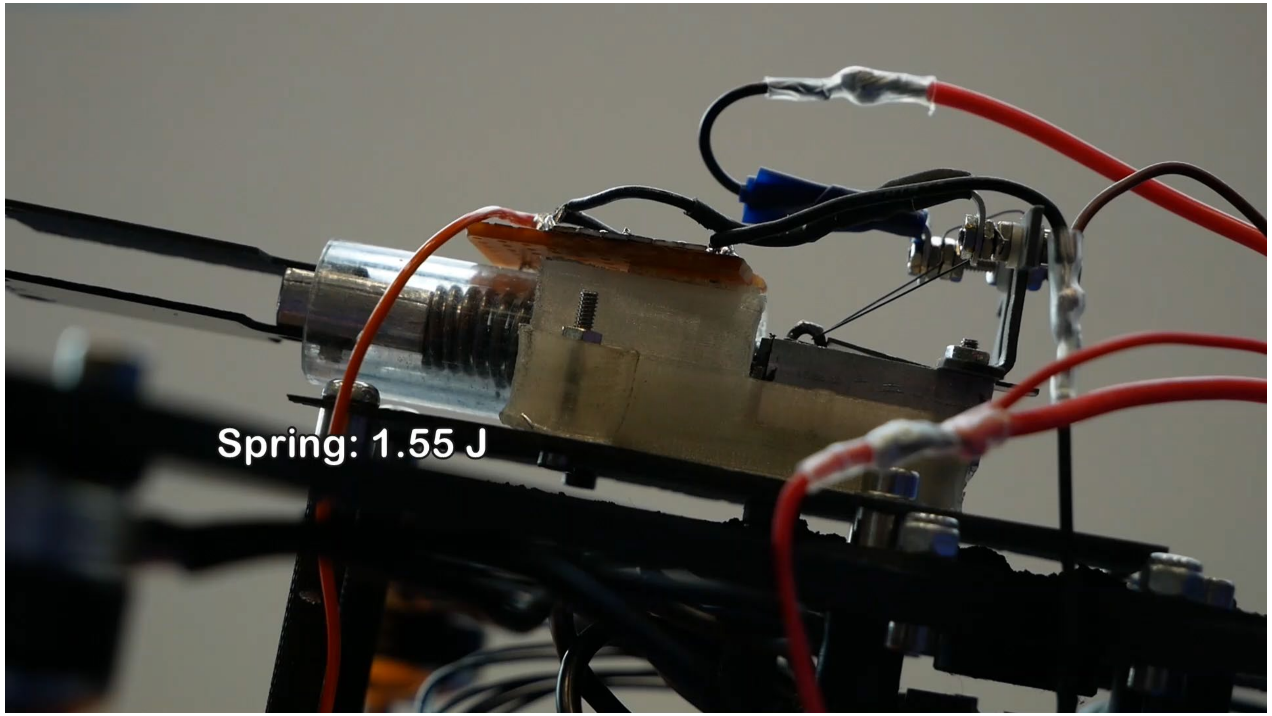
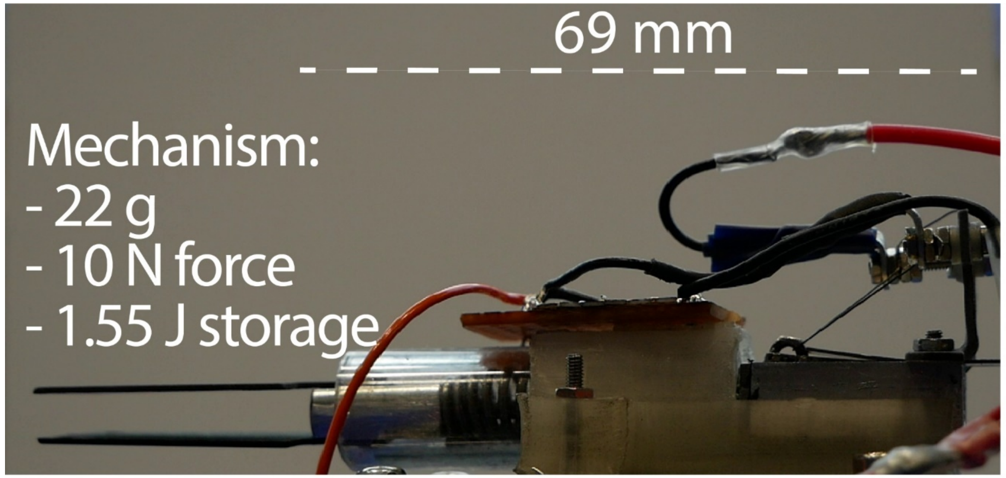
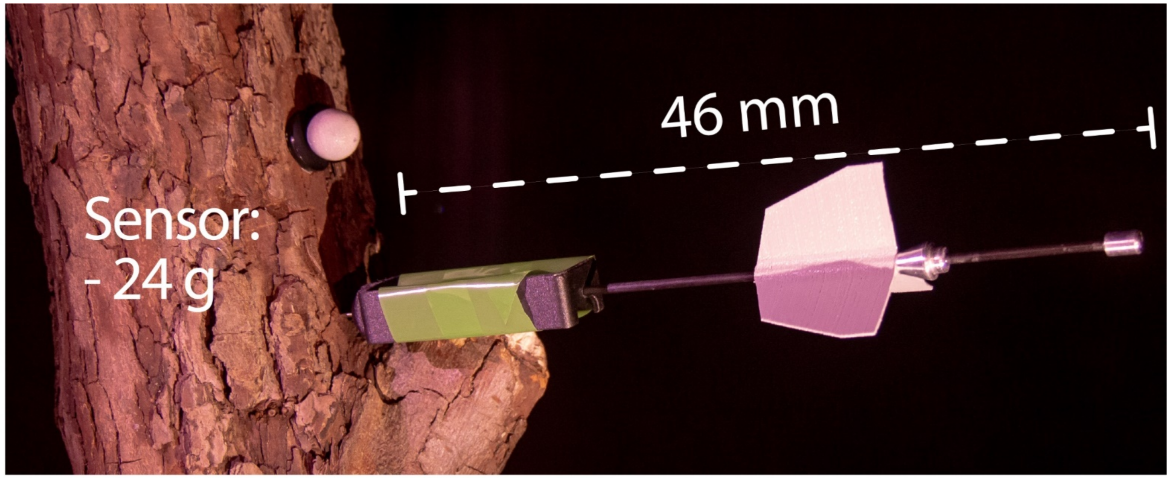
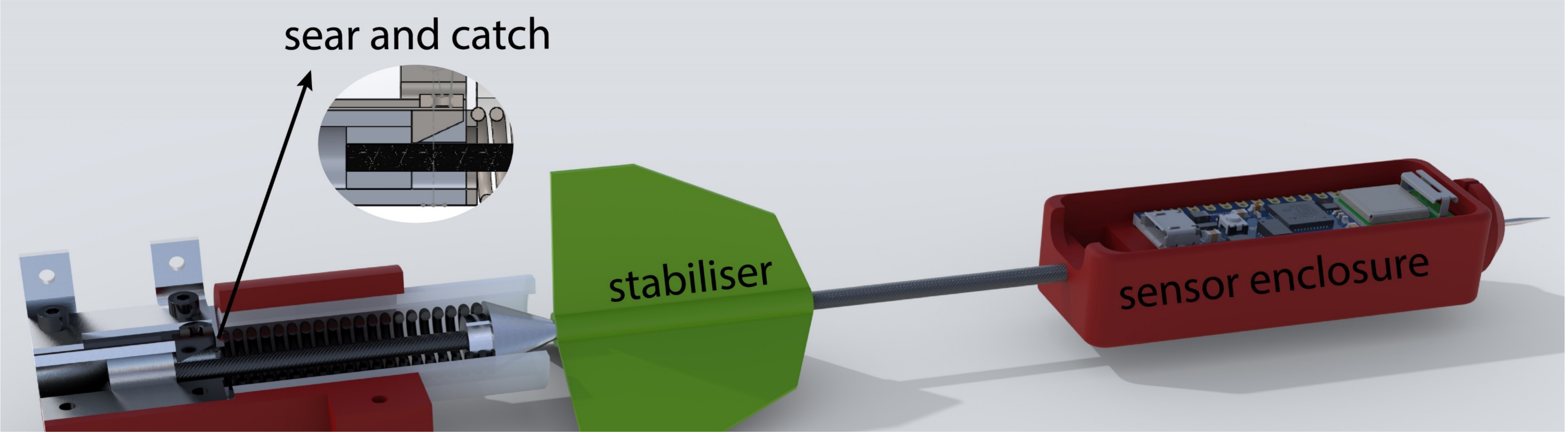




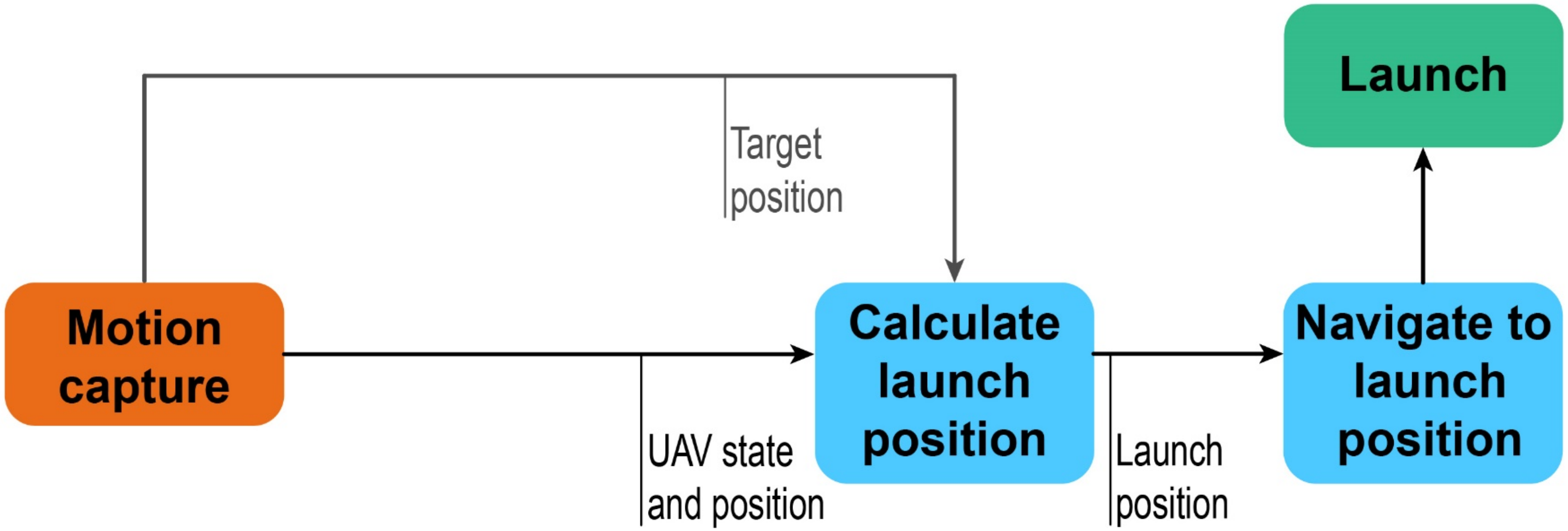
System Features







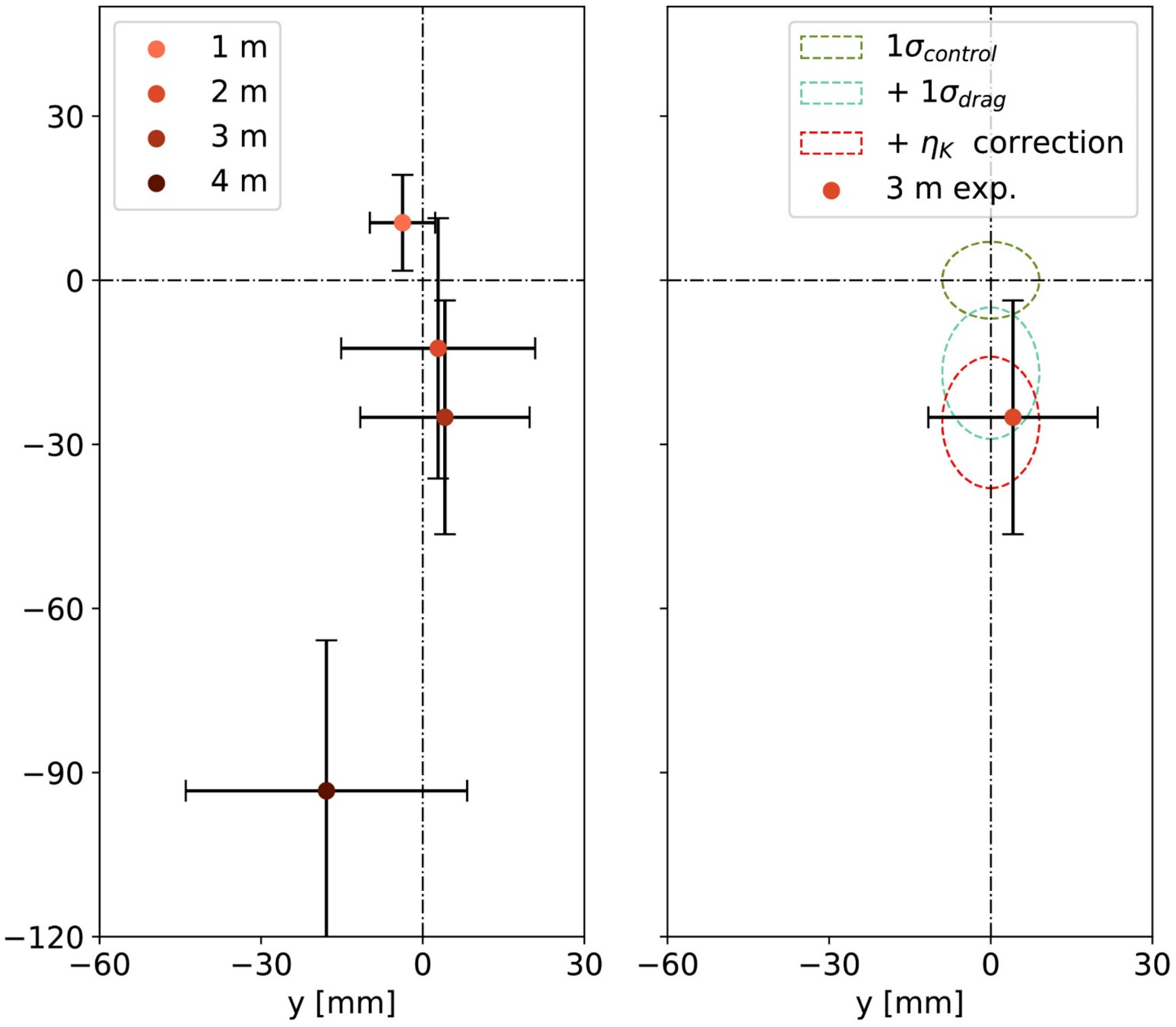
Sensor Launching Sequence

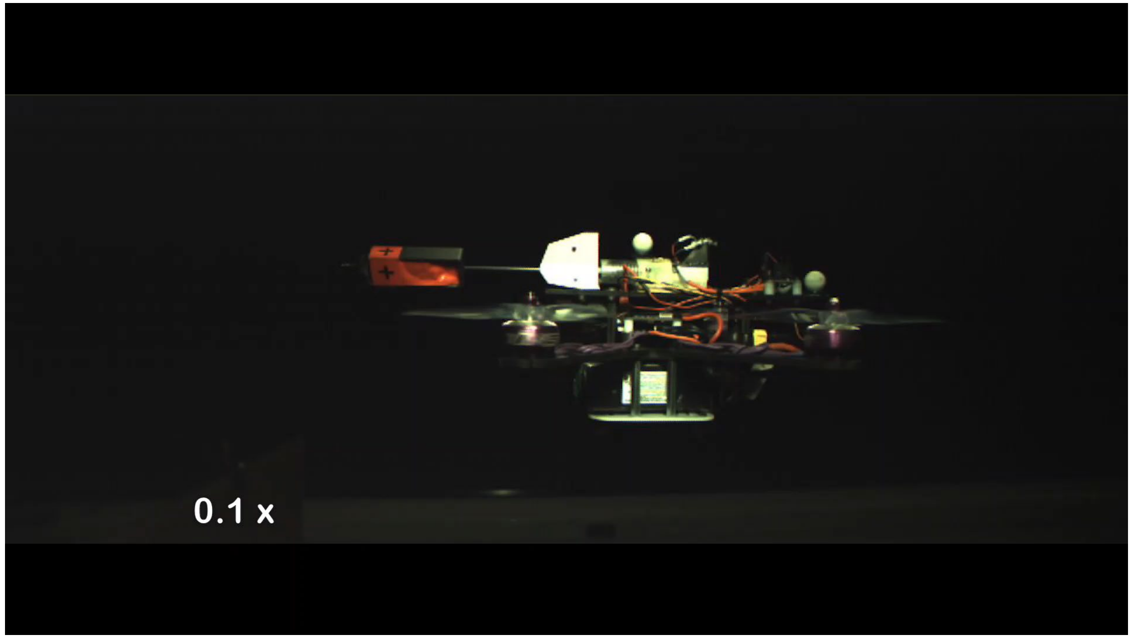


- ❖ 64 tests onto a flat ferromagnetic surface
- ❖ 5 tests onto a ferromagnetic pipe
- ❖ 12 tests onto a wooden branch
- ❖ 2 tests outdoors

Sensor Launching

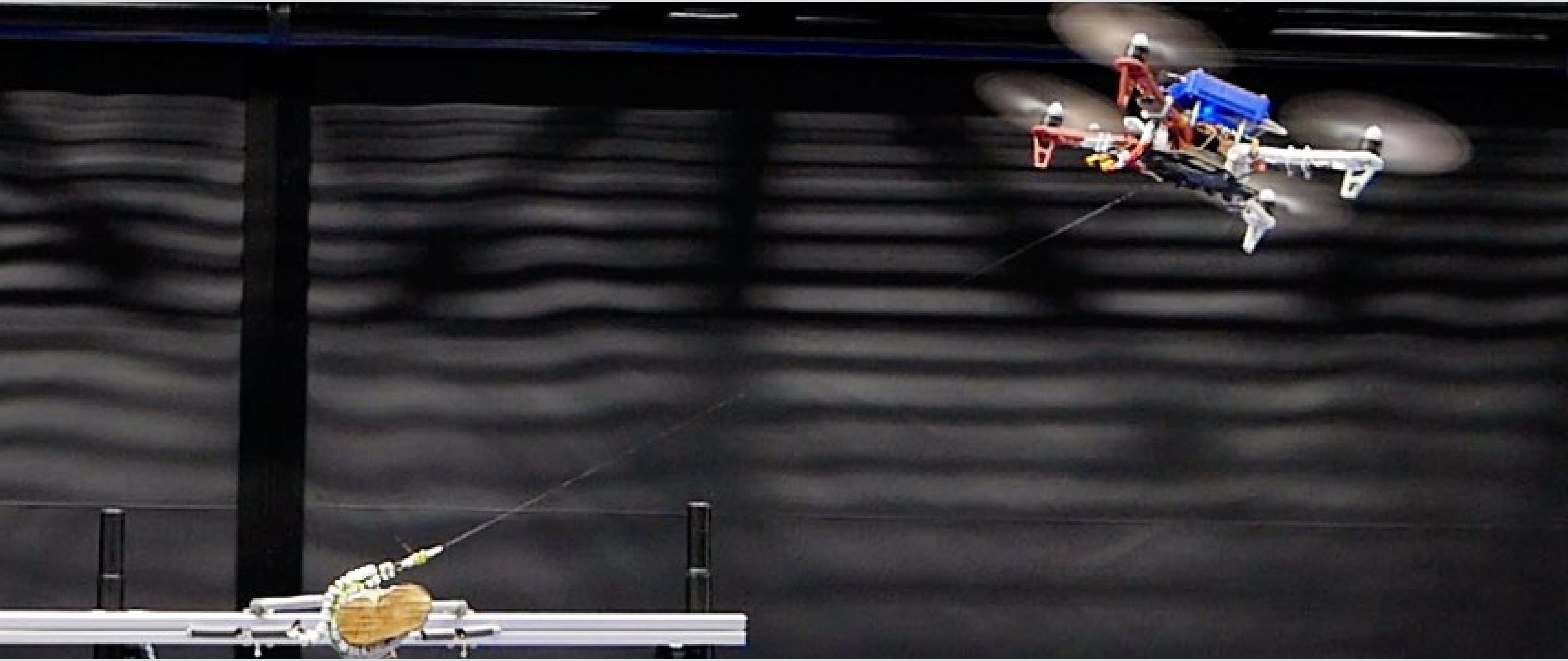
Positioning Accuracy





- 80% mechanical energy conversion achieved
- improved results using tails stabilisers

Perching on trees



H. Nguyen, R. Siddall, B. Stephens, A. Navarro-Rubio and M. Kovač, "A Passively Adaptive Microspine Grapple for Robust, Controllable Perching," 2019 2nd IEEE International Conference on Soft Robotics (RoboSoft), Seoul, Korea (South), 2019, pp. 80-87

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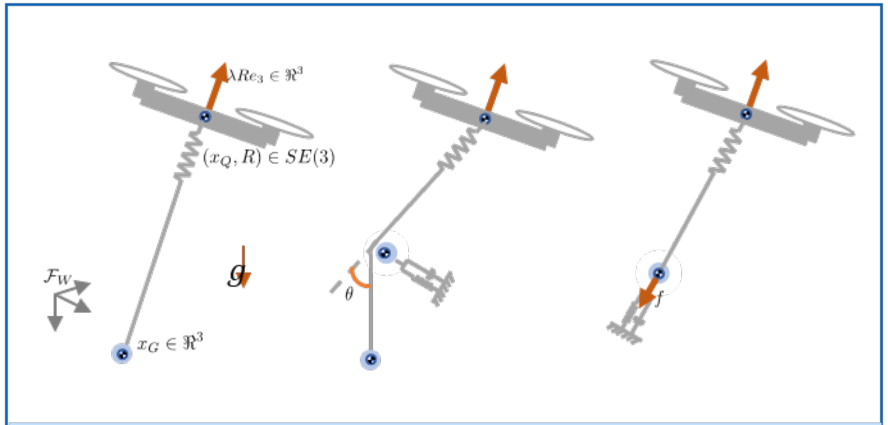
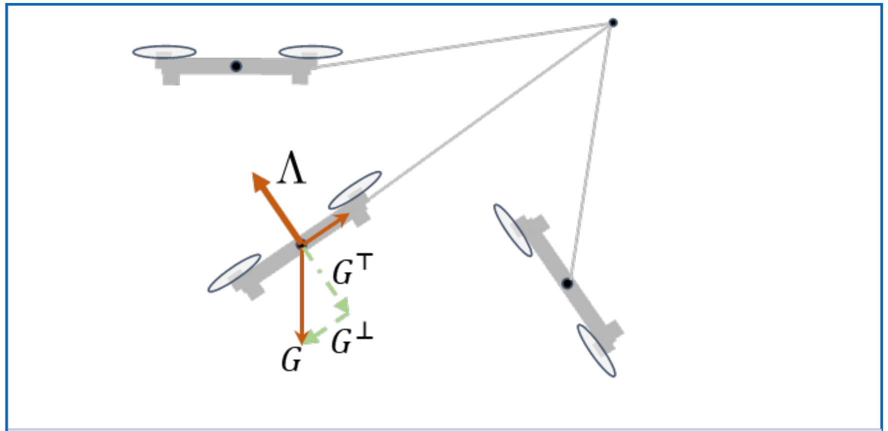
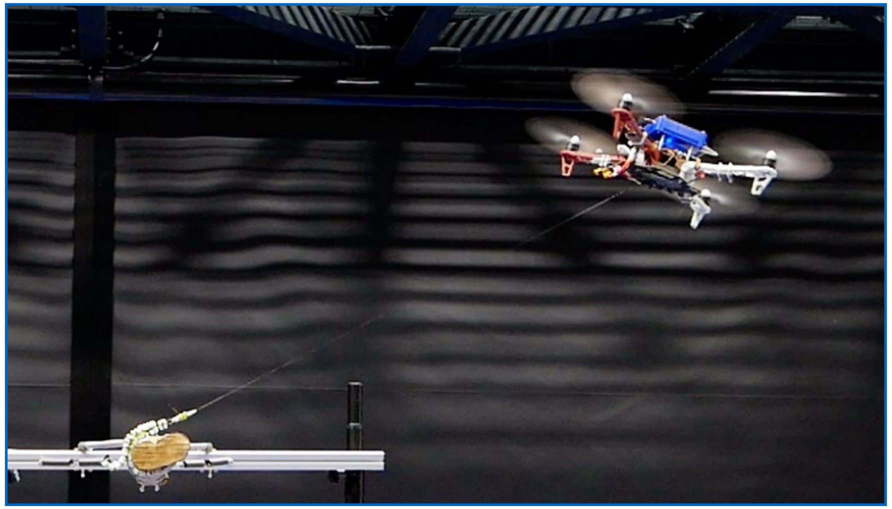
Perching on Trees

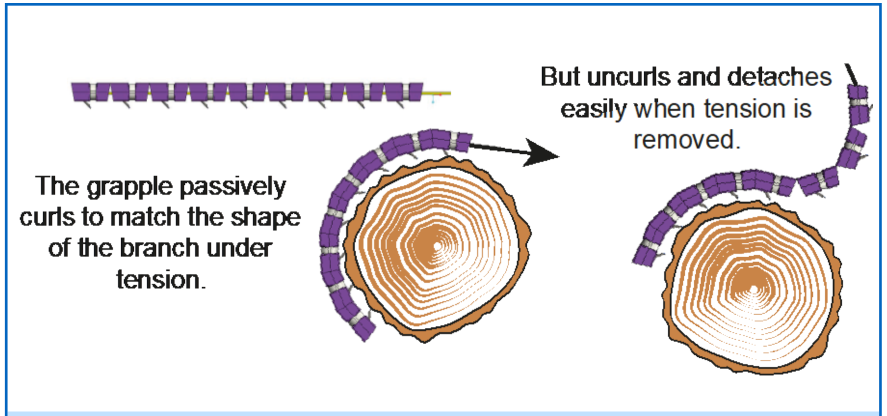


Perching for long-term surveillance



Energy efficiency

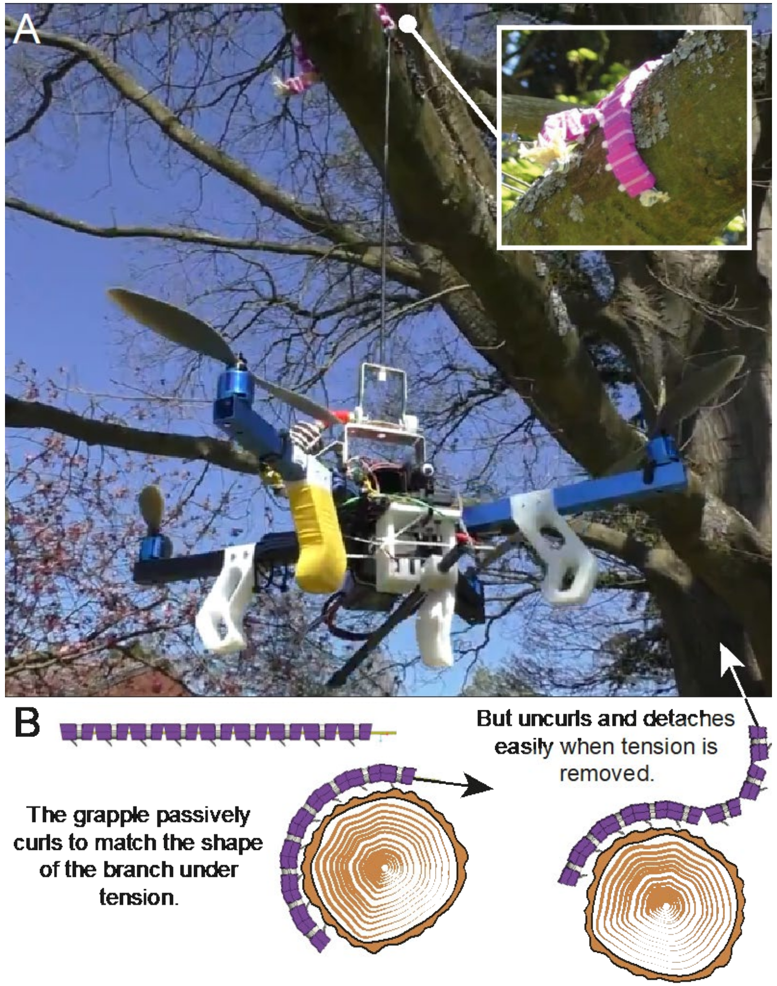


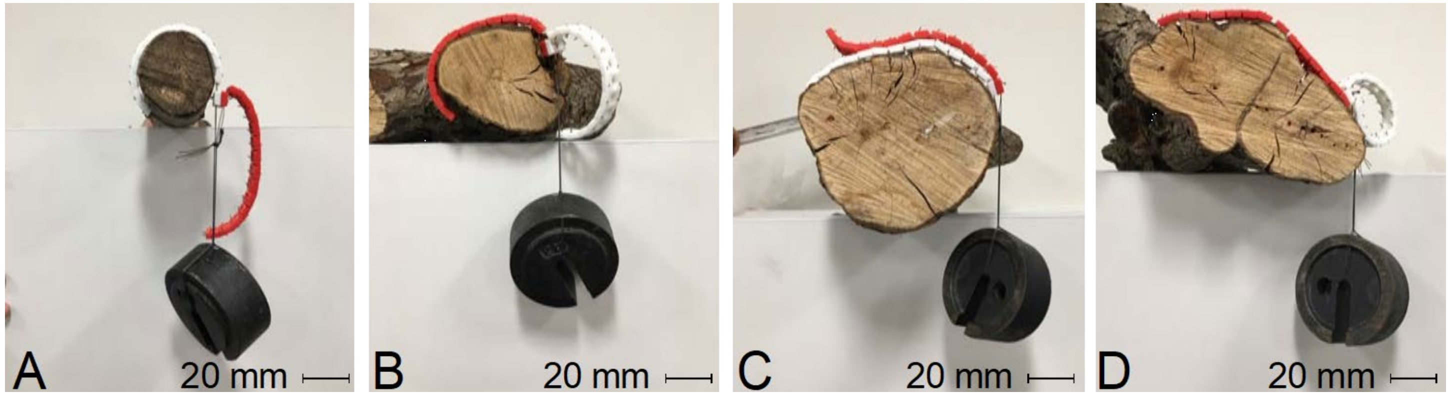


Passive-adaptive grapple

Passive Adaptive Grapple

lightweight, high payload & adapted to irregular shapes

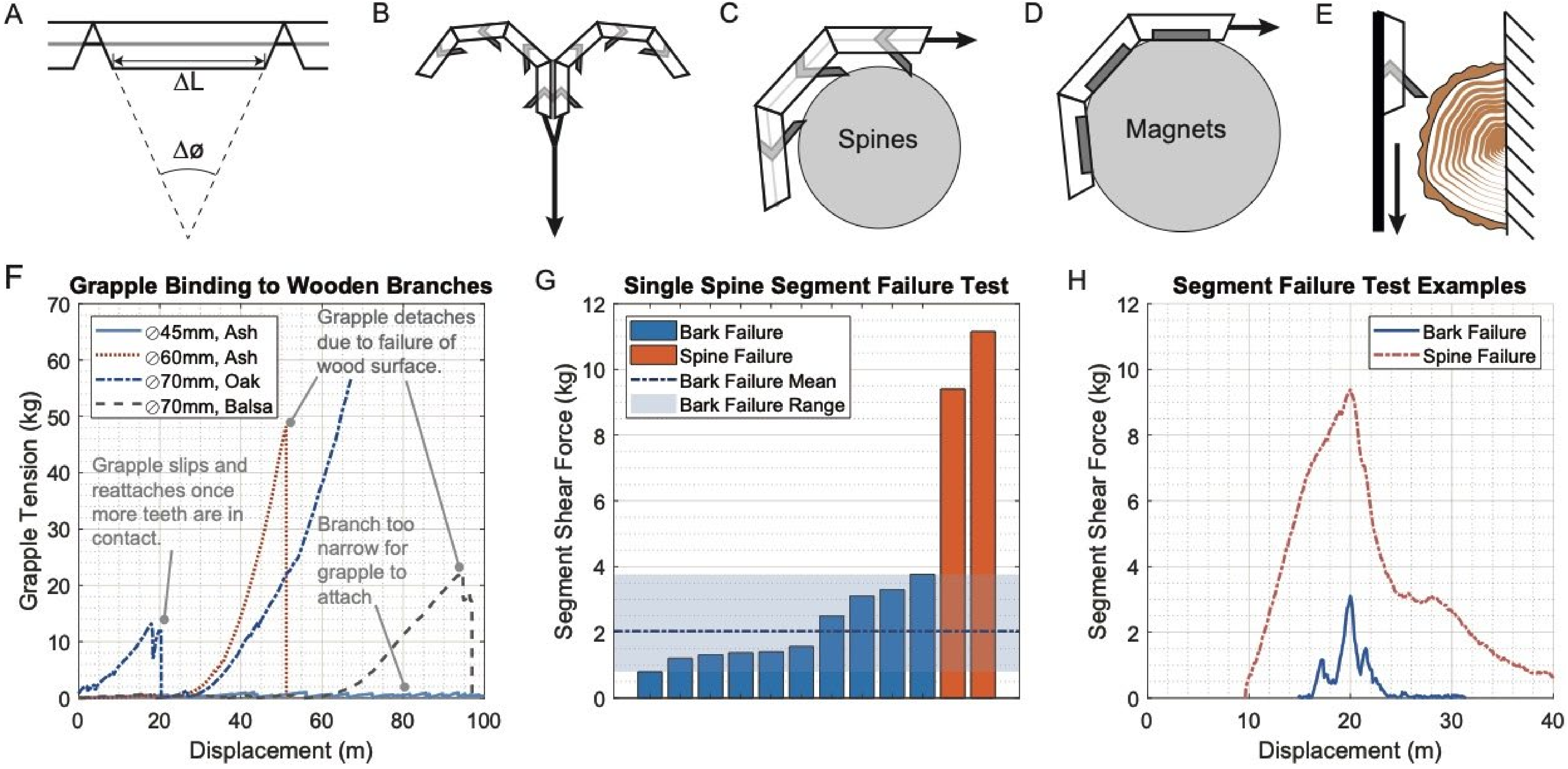




Component	Mass (grams)	/Total
Quadrotor Airframe	866	47 %
Battery (4S 2200mAh)	218	12 %
Computing (NUC)	602	33 %
Winch System	108	6 %
Grapple	32	2 %
Total	**1766**	**100 %**

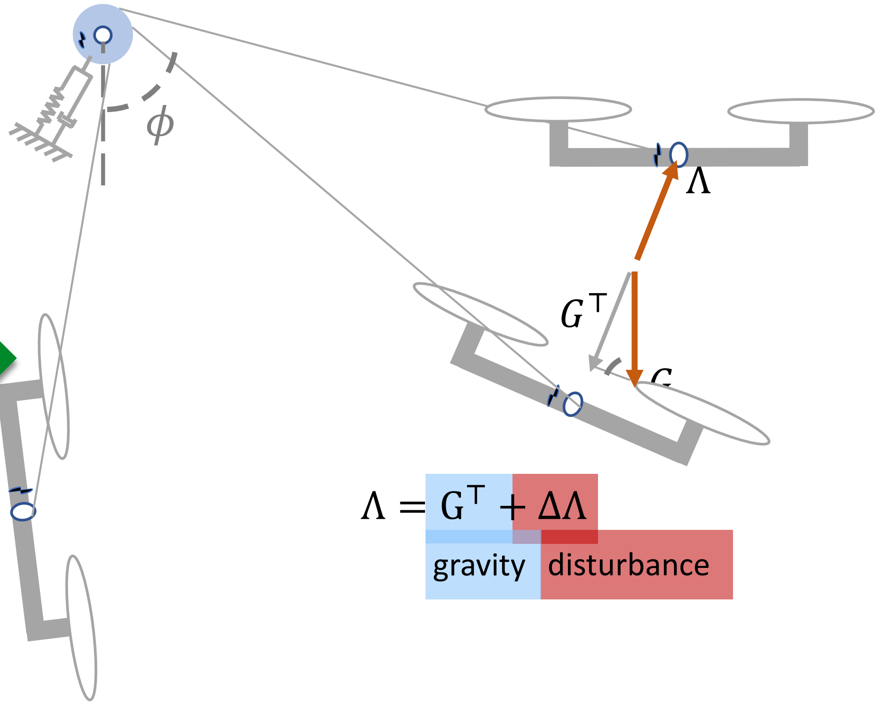
Passive Adaptive Grapple

lightweight, high payload & adapted to irregular shapes



Tensile Perching Sequence

Energy Efficiency

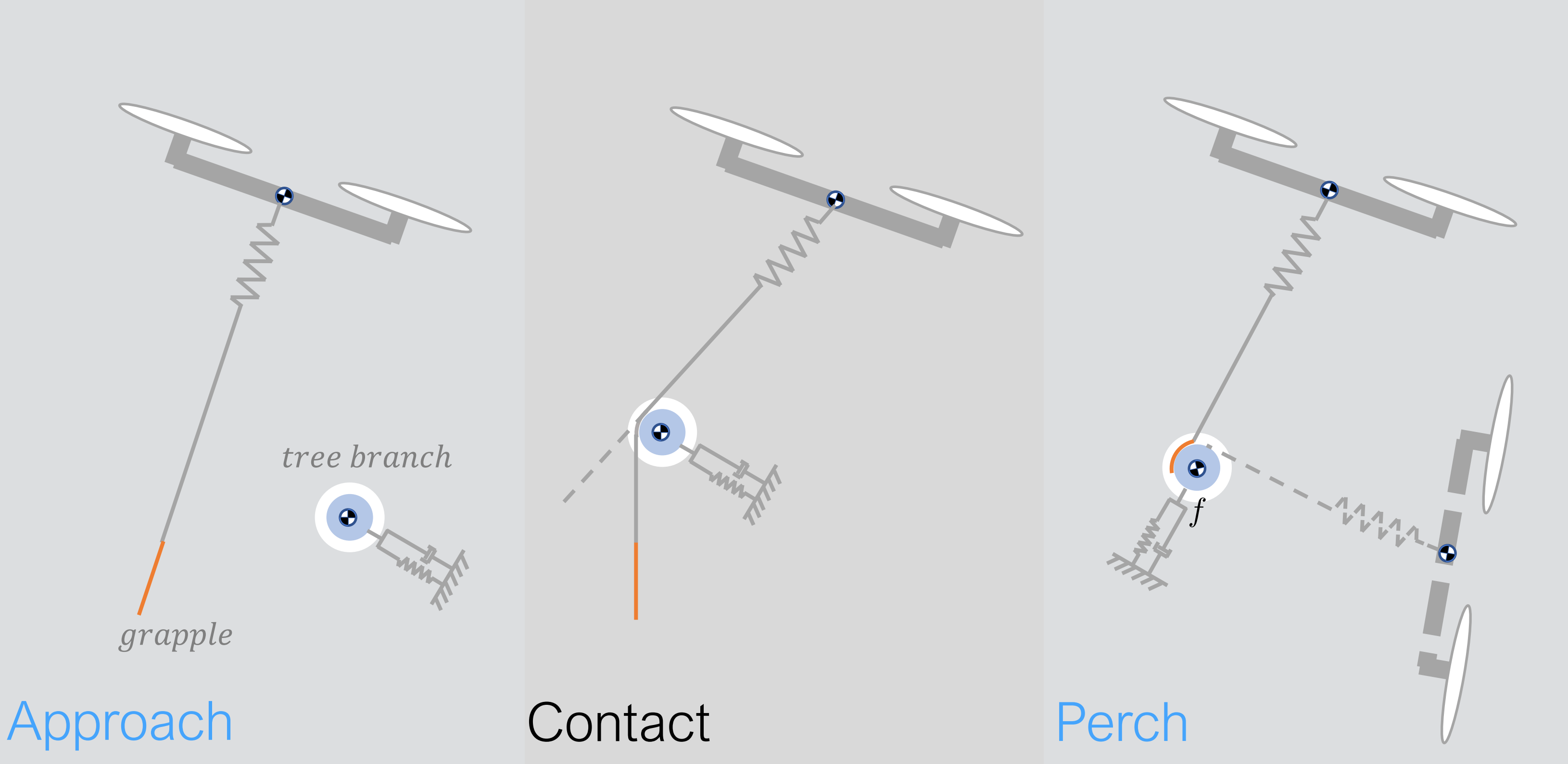


tethered hovering thrust $\Lambda = G^\top + \Delta\Lambda = \sin\phi\, G + \Delta\Lambda$

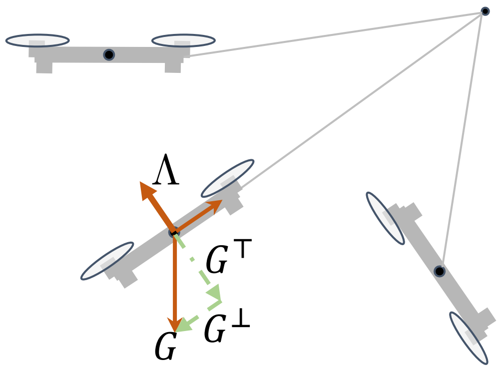
- at 30°: save 50% the energy
- at 10°, save more than 80%

Tensile Perching Sequence

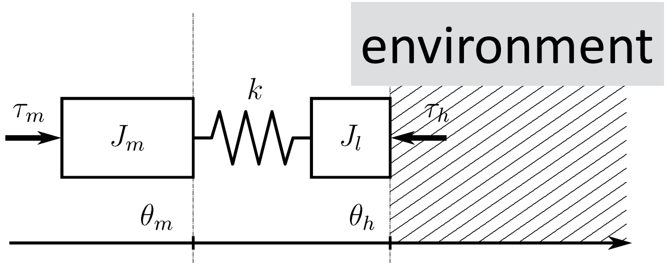
Compliant contact model



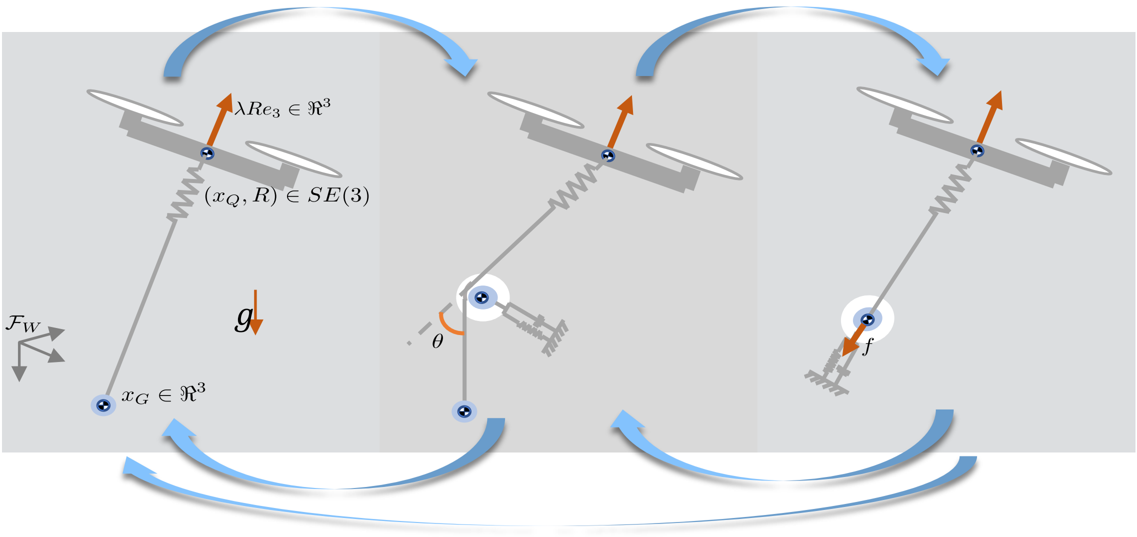
Perching Control Strategy



Rotational motion

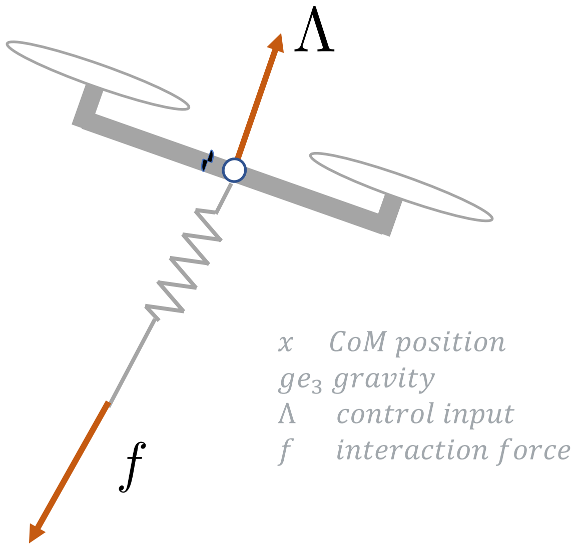


Tensile interaction



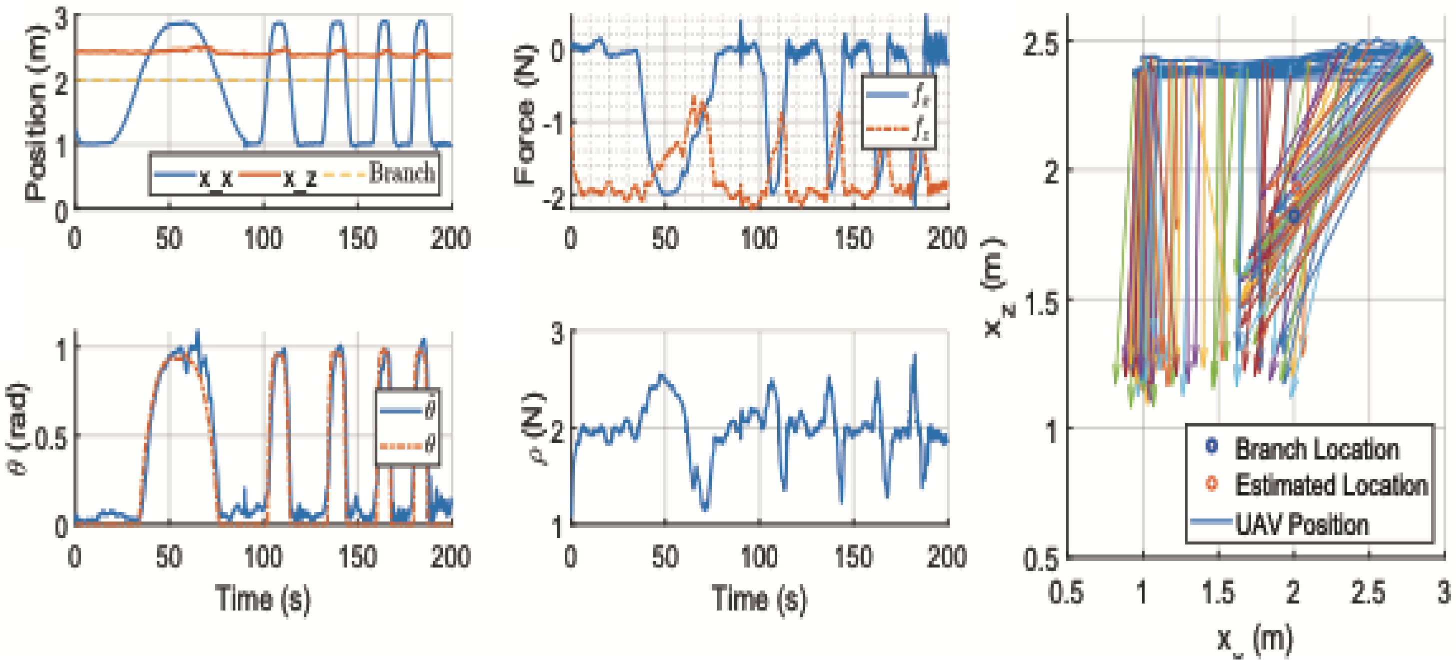
Tactile-based mode switching

String-based Tactile Sensing

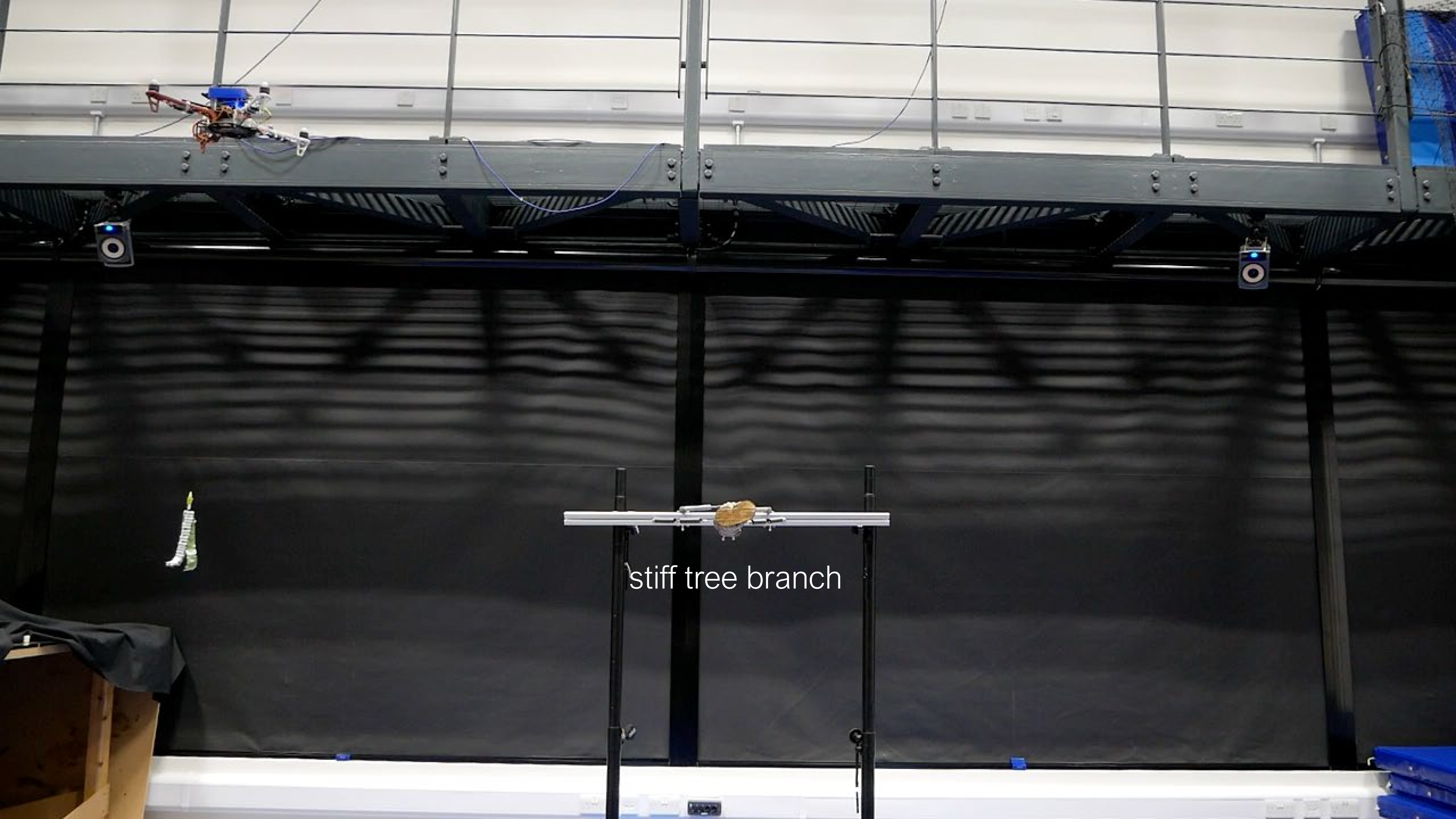


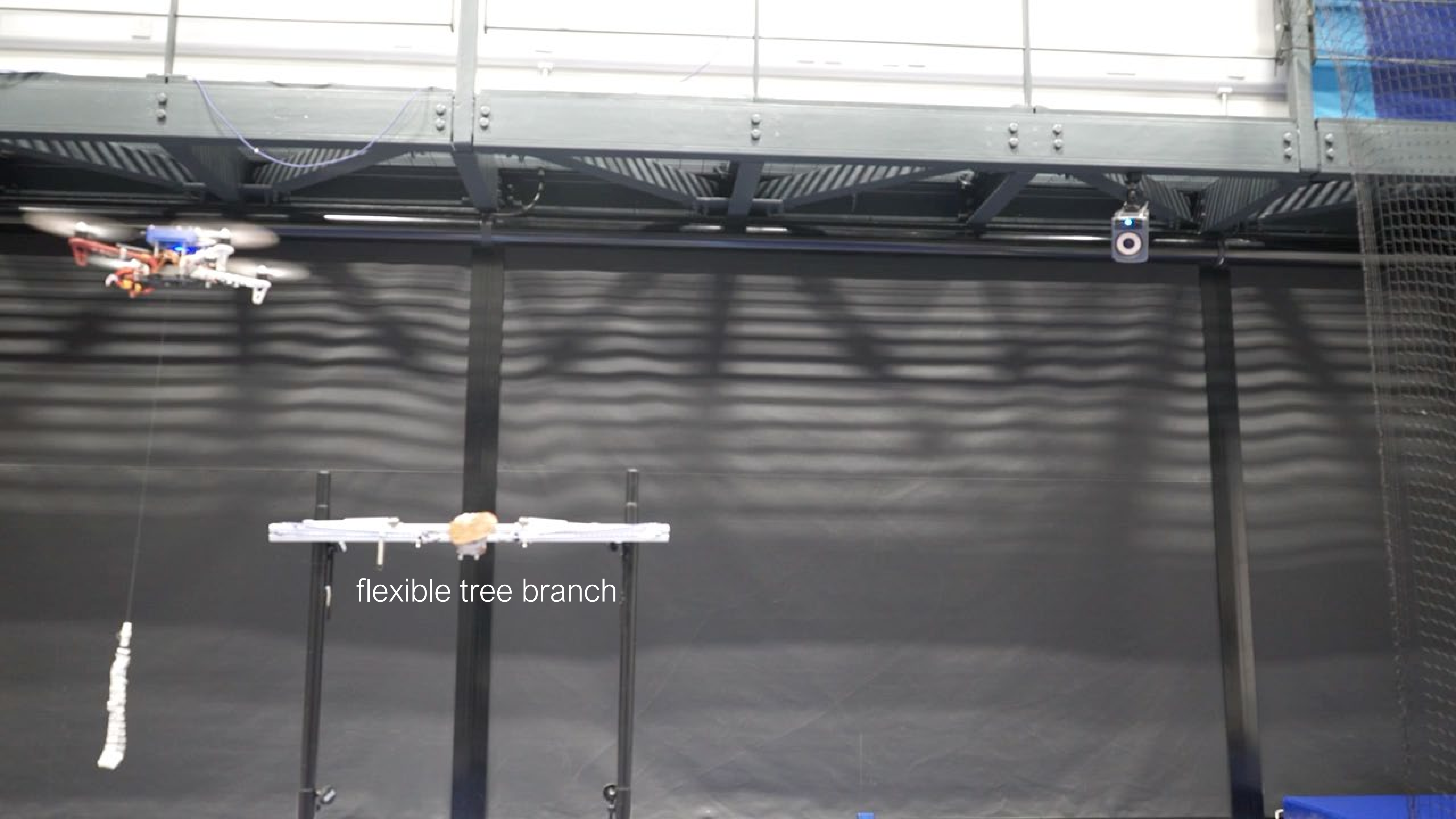
$m\ddot{x} - mge_3 = \Lambda$	$+ f$
measured & known	unknow

tensile force estimation



Approaching to estimate branch location


stiff tree branch


flexible tree branch

Conclusions

- UAVs are ideal for forest diagnostics as these can cover large areas and are agile enough to operate below the canopy.

- UAVs enable the characterisation of forests as a three dimensional environment.

- Sensor placement with UAVs increases the temporal resolution of datasets increasing their relevance for environmental studies.

- The presented methods can carry out diverse mission profiles, targeting different locations of interest in forests’ structure.

Acknowledgements

HORIZON 2020

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Imperial College London

THE ROYAL SOCIETY

Royal Society
Wolfson Fellowship

[dstl]

ADIA
Abu Dhabi Investment Authority

Empa
Materials Science and Technology

Imperial College London

Rethinking Robotics for the Robot Companion of the future
RoboCom++

Office of Naval Research GLOBAL Science & Technology

Grantham Institute for Climate Change
An institute of Imperial College London

NERC
SCIENCE OF THE ENVIRONMENT

EPSRC
Engineering and Physical Sciences Research Council

Aerial Additive Building Manufacturing (ABM) Research Grant
01/05/2016 - 30/04/2020, £3.4m
5 UK academic partners + 5 industrial project partners

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UNIVERSITY OF BATH

SMART ROBOTICS LAB

Architectural Association School of Architecture

UCL

EPSRC
Engineering and Physical Sciences Research Council

Aquatic Micro Aerial Vehicles (AquaMAV) Research Grant
01/06/2016 - 31/12/2016, £123,194

EPSRC
Engineering and Physical Sciences Research Council

CASCADE Program Grant
01/02/2018 - 31/01/2021, £4.45m
5 UK academic partners + 26 project partners

University of Southampton

University of BRISTOL

Imperial College London

Cranfield University

MANCHESTER 1824
The University of Manchester

EPSRC
Engineering and Physical Sciences Research Council

ORCA HUB in the ISCF - Industrial Strategy Research Fund
02/10/2017 - 01/04/2021, £14.6m
5 UK academic partners + 31 industrial project partners

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HERIOT WATT UNIVERSITY

THE UNIVERSITY of EDINBURGH

Imperial College London

UNIVERSITY OF OXFORD

UNIVERSITY OF LIVERPOOL

EPSRC
Engineering and Physical Sciences Research Council

Applied off-site and on-site collective multi-robot, autonomous building manufacturing
01/01/2019 - 31/12/2021, £1.2m
2 UK academic partners + 6 industrial project partners

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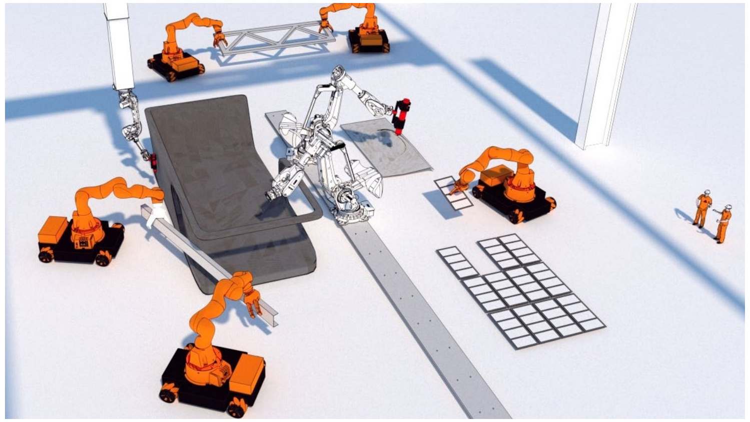

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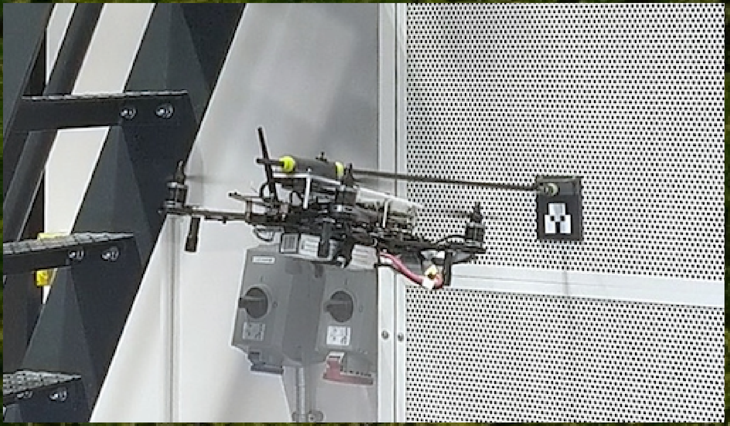

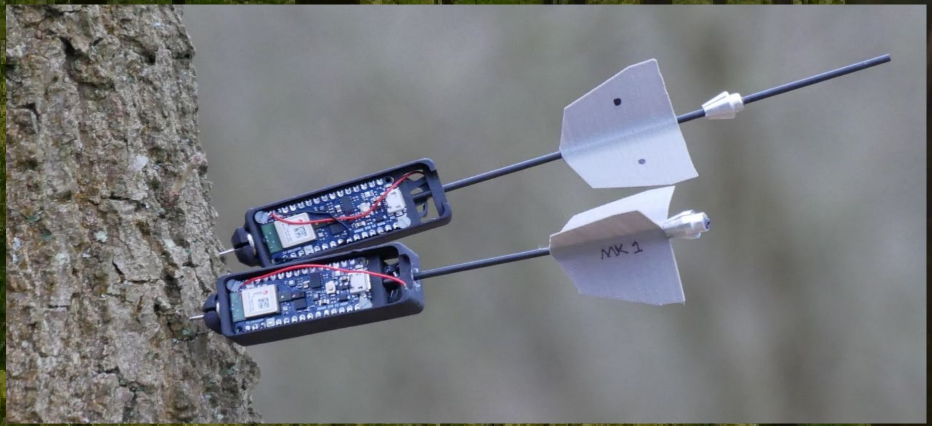

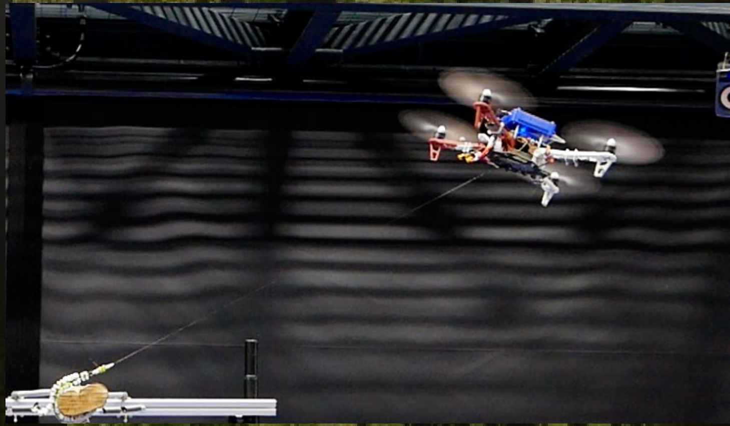

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