Autonomy as an enabler for the Next Generation of Space Robotics Exploration Missions

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WHO ARE WE?

www.ltu.se/robotics

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ROBOTICS TEAM
at Luleå University of Technology


Prof. George Nikolakopoulos
Head of Robotics Team


Dr. Christoforos Kanellakis
Assistant Professor


Dr. Avijit Banerjee
Post-Doc


Dr. Georgios Georgoulas
Visiting Researcher


Dr. Anton Koval
Post-Doc


Dr. Rucha Sawlekar
Post-Doc

+7 Post Docs


Akshit Saradagi,
Post-Doc


Summeet Satpute
Post-Doc


Björn Lindqvist
PhD Student


Samuel Karlsson
PhD Student


Andreas Papadimitriou
PhD Student


Yifan Bai
PhD Student


Achilleas Seisa,
PhD Student


Vignesh Kottayam Viswanathan
PhD Student


Moumita Banarjee
PhD Student


Akash Patel
PhD Student

+5 PhD Students


Ilias Tevetzidis
Research Engineer


Jakub Haluska
Research Engineer


Dariusz Kominiak
Research Engineer

We are 31 people

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RAI World-Wide Collaborations

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Robotics & AI Team, LTU - Applications

- Autonomous robots for inspection
  - Wind turbines & power lines
  - Airplanes
  - Hard to reach and dangerous missions (fires, avalanches, nuclear reactors)
- Sustainability and efficiency in mining operations
- Ensuring the safety and security of persons during dangerous operations
- Robots for support, medical assistance, and search-and-rescue




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RAI AREAS OF PRIMARY FOCUS

- Aerial robotics
- Inspection robotics
- Space robotics
- Service robotics
- Autonomous cars
- Soft Robotics
- Industrial robotics
- Robotized farming
- Construction robotics
- Marine robotics
- Underwater robotics

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The Nebula Autonomy

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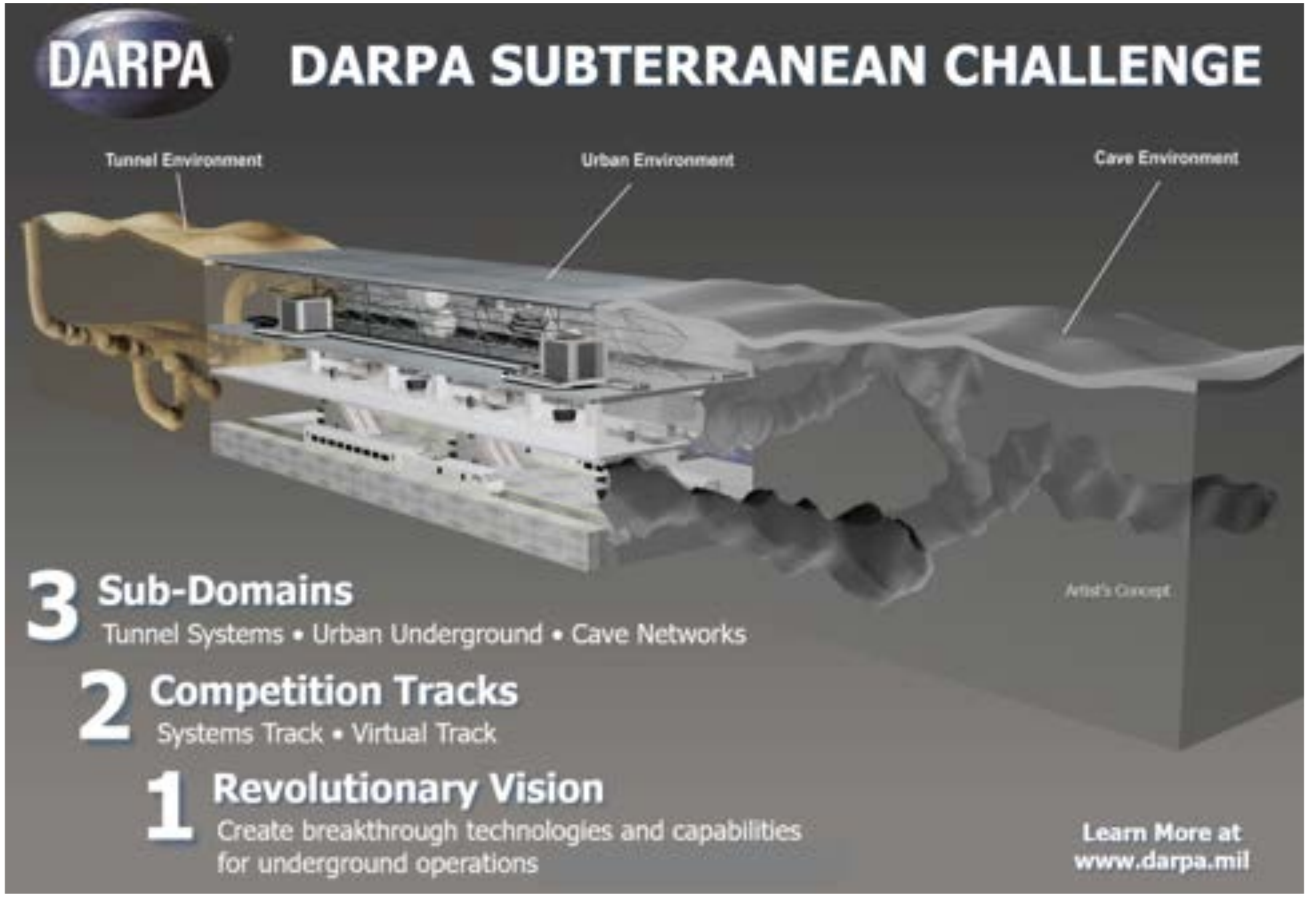
The DARPA SUB-T COMPETITION



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WE HAVE WON THE 2nd STAGE OF DARPA SUB-T COMPETITION

IEEE SPECTRUM Topics Reports Blogs Multimedia Magazine Resources Search

Late Nights, Cool Hacks, and More Stories From the DARPA SubT Urban Circuit

Everything you didn't see on the live stream at the DARPA SubT Challenge

By Evan Ackerman

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Jet Propulsion Laboratory
California Institute of Technology

Massachusetts Institute of Technology

KAIST 1971

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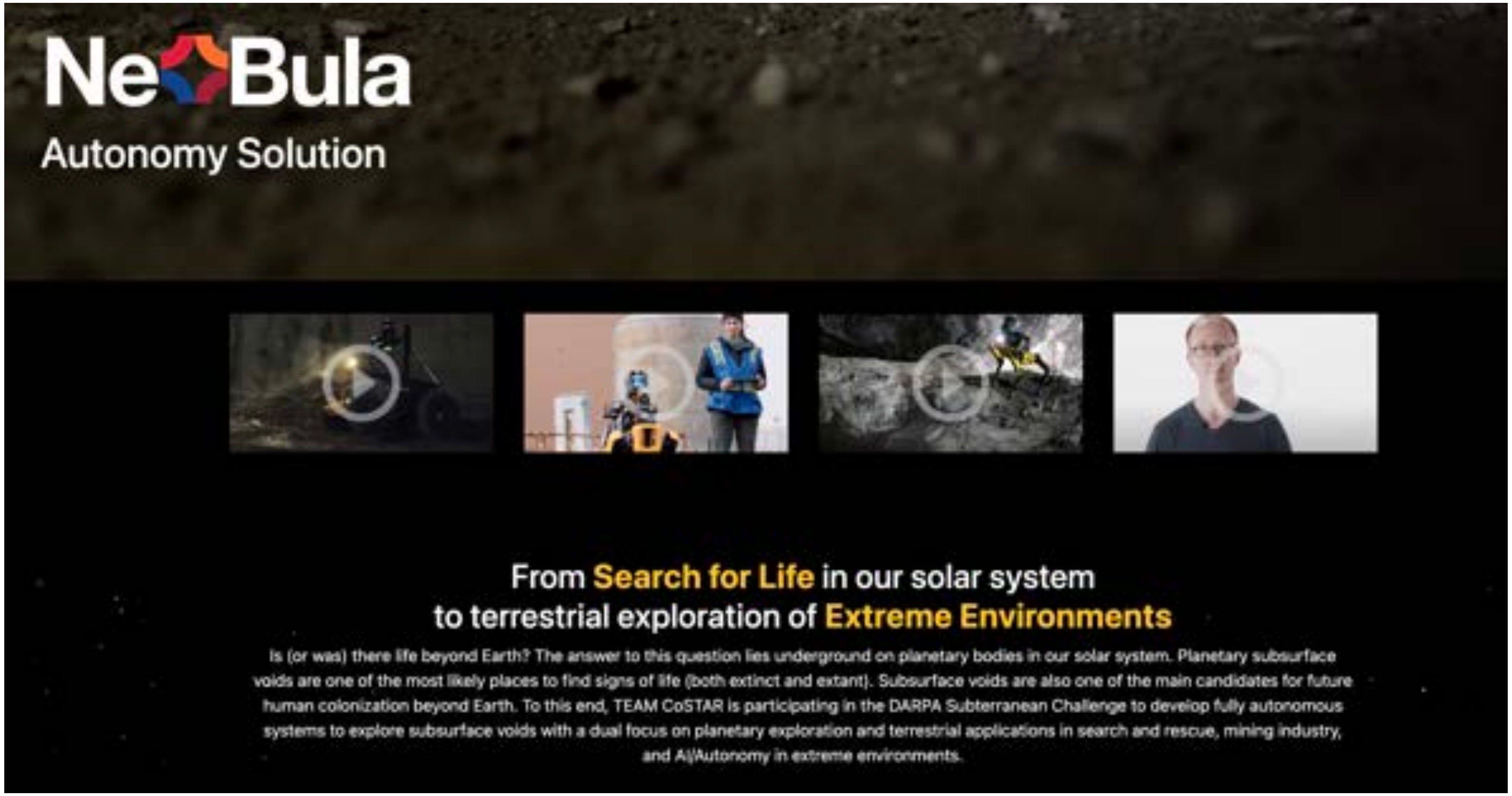
The NeBula Autonomy Solution

https://costar.jpl.nasa.gov/



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NeBula: Quest for Robotic Autonomy in Challenging Environments; TEAM CoSTAR at the DARPA Subterranean Challenge, Journal of Field Robotics, 2021

The NEBULA Autonomy Solution

Autonomous Exploration of Extreme Environemts

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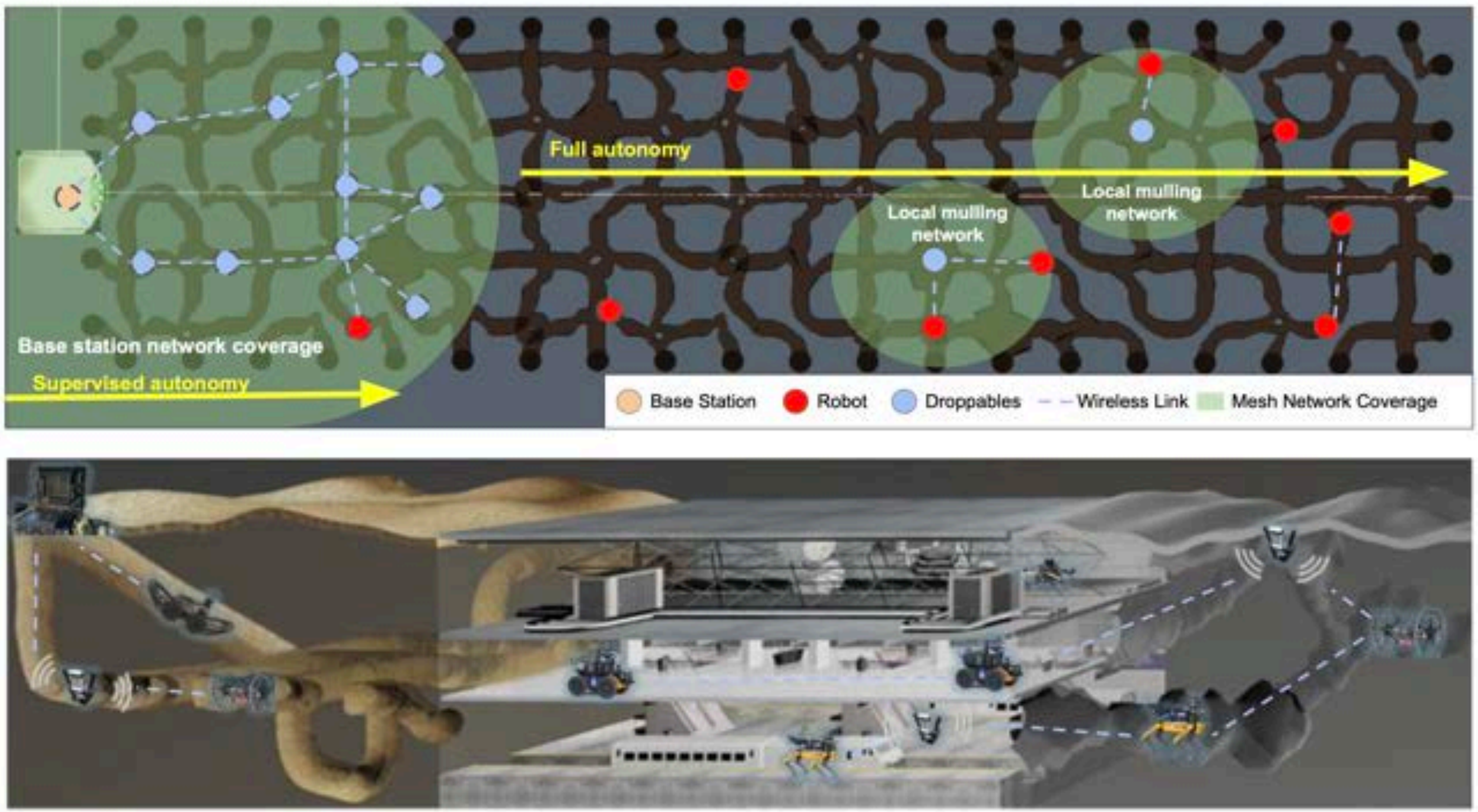
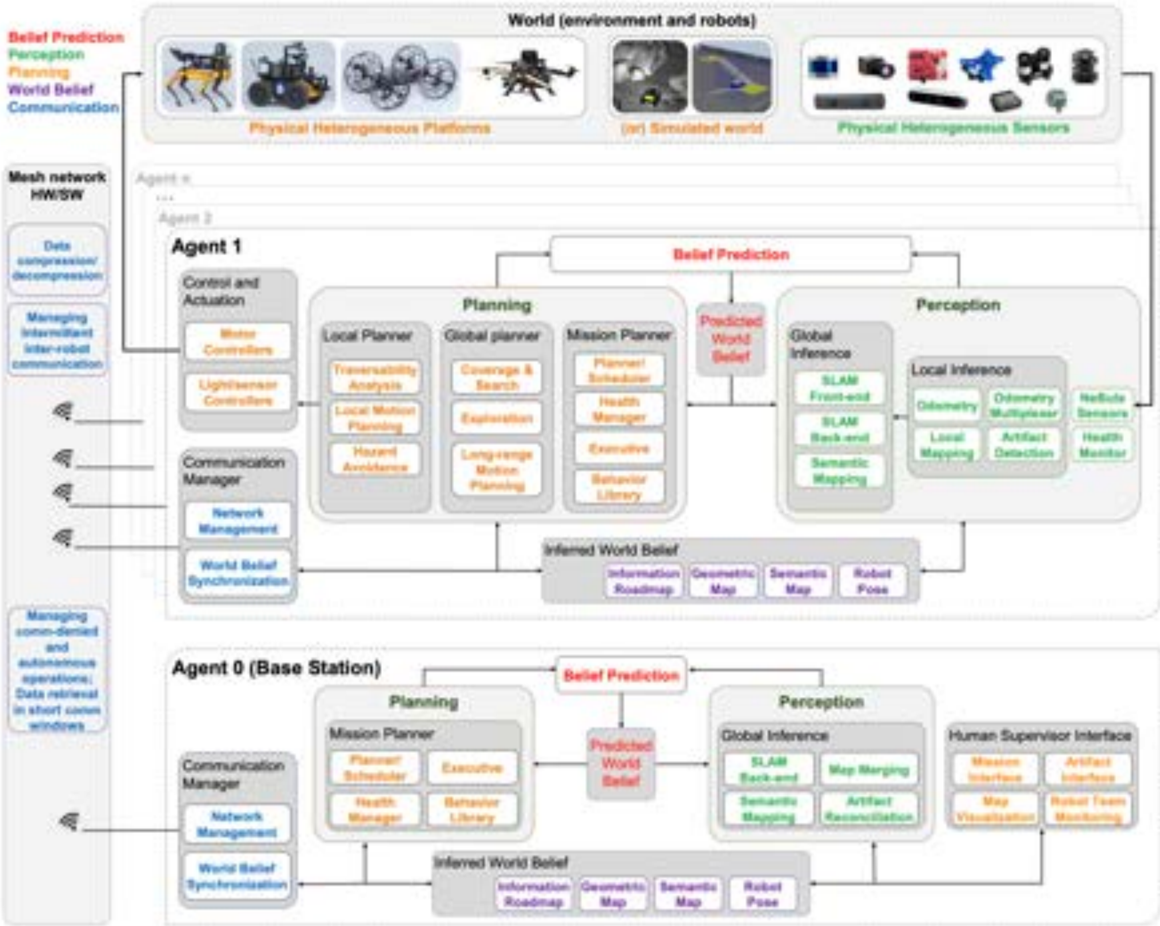
The SubT competition

Multi-Robotic Orchestration



NeBula: Quest for Robotic Autonomy in Challenging Environments; TEAM CoSTAR at the DARPA Subterranean Challenge, Journal of Field Robotics, 2021

Extreme Autonomy in Multi-Modal Robotic Platforms



NeBula: Quest for Robotic Autonomy in Challenging Environments; TEAM CoSTAR at the DARPA Subterranean Challenge, Journal of Field Robotics, 2021

Autonomy for SubT planetary bodies exploration

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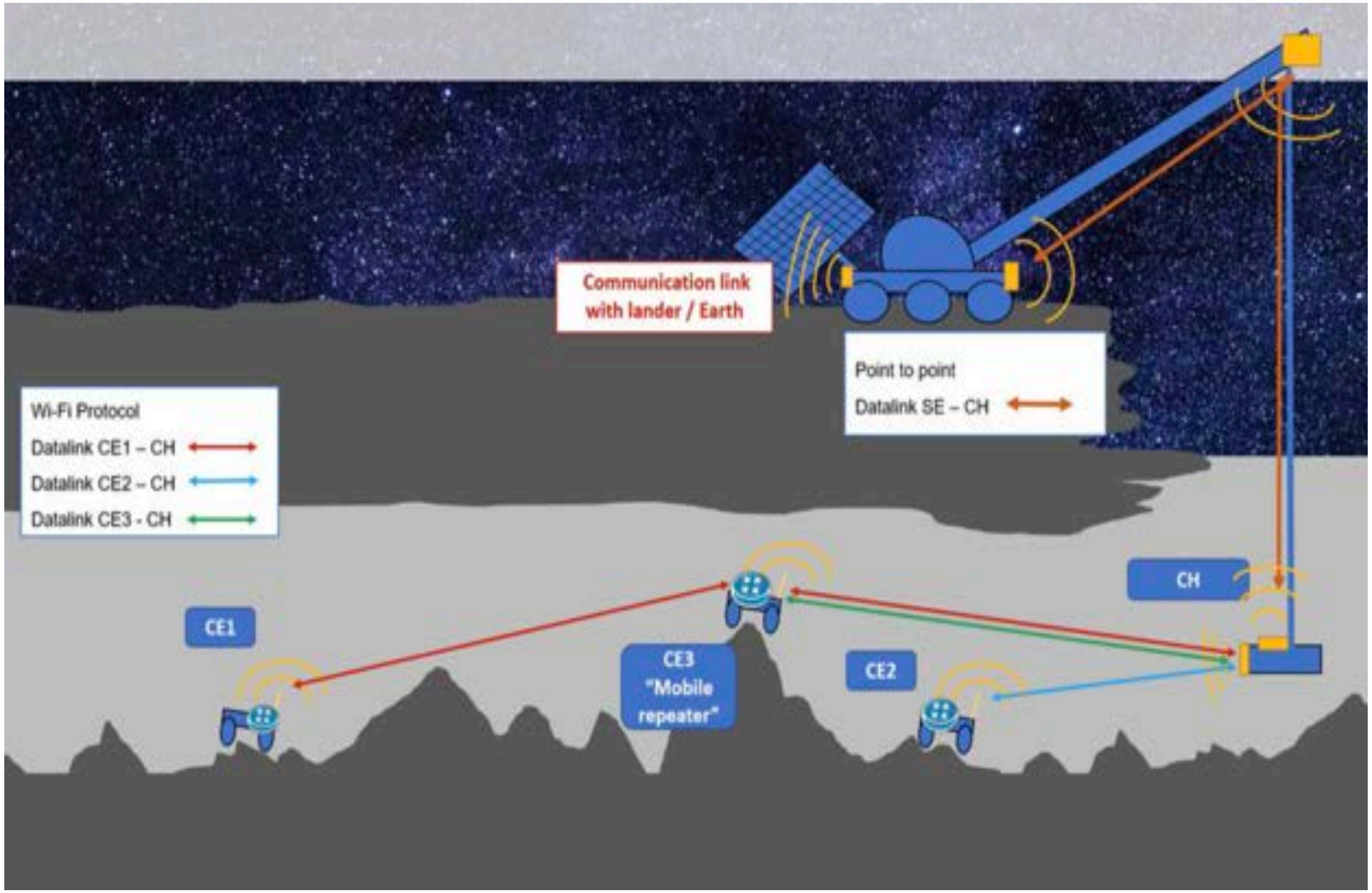
ESA call for concepts on Lava tubes exploration



Field Autonomy for UAVs - I

Full Exploration Mission on UAVs - III

Field Autonomy for legged Robotics

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Embodied Autonomy: the hidden hero!

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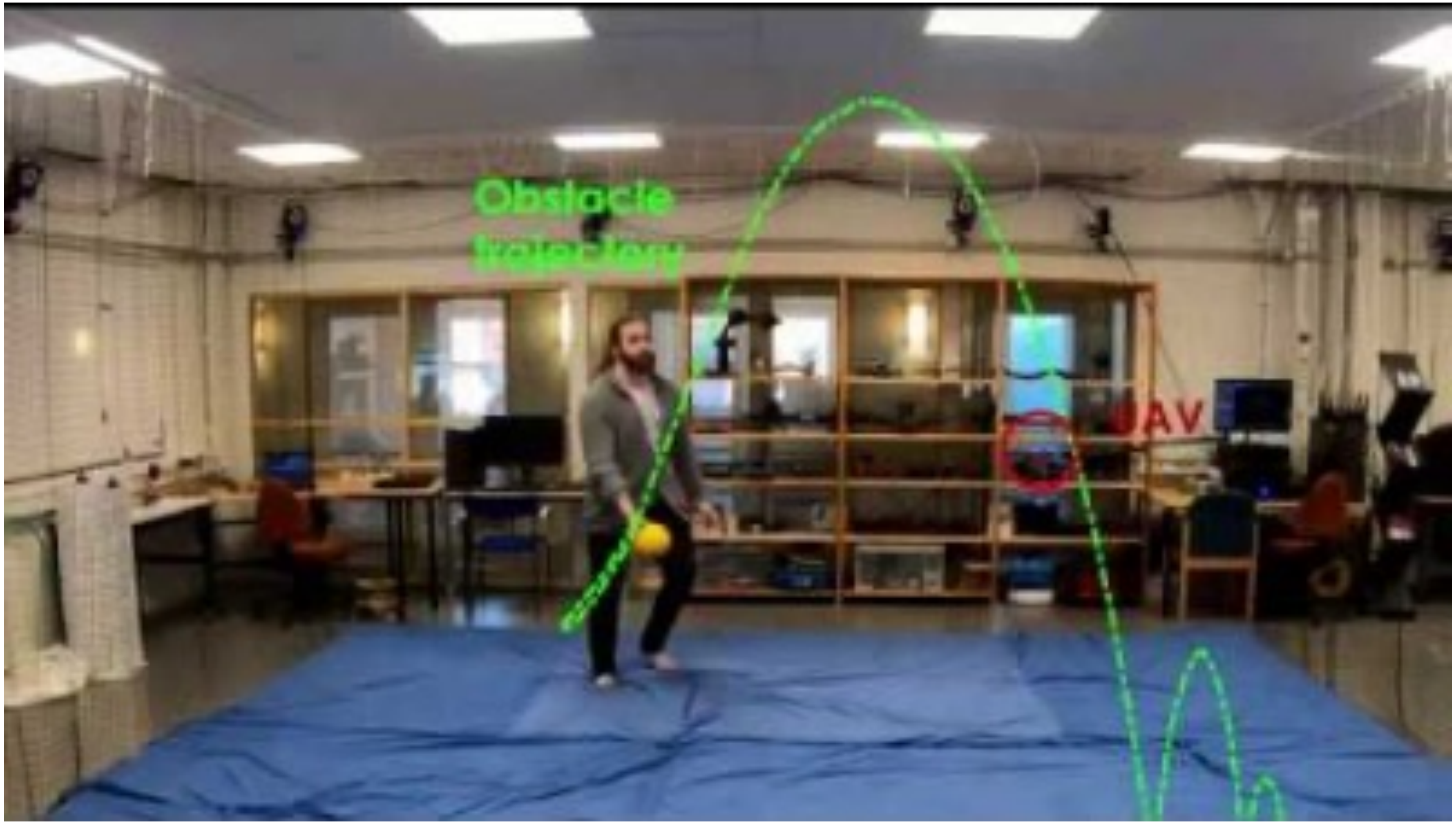
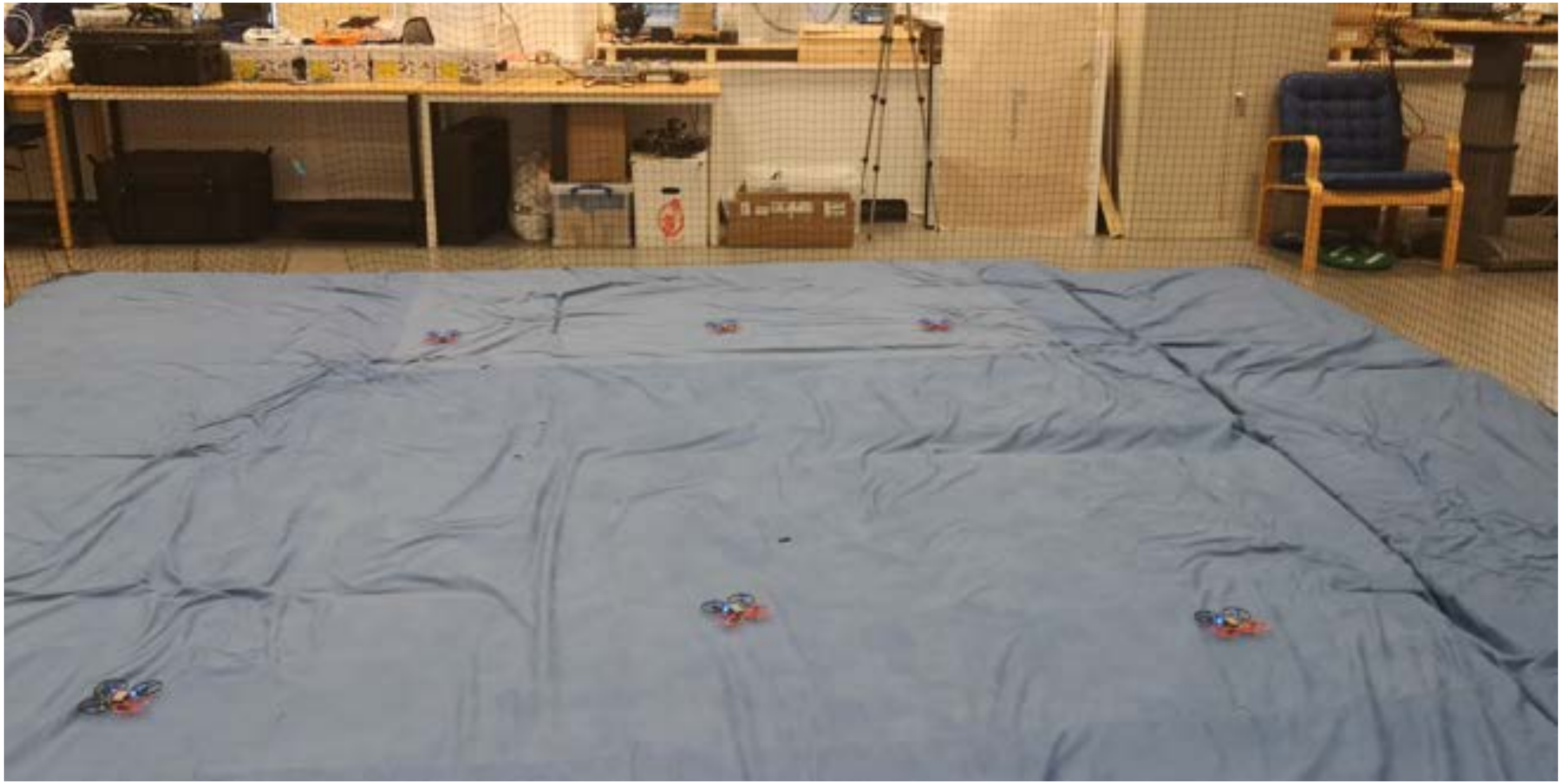
Onboard Full Autonomy I



Onboard Full Autonomy II



Onboard Full Autonomy II

Reactive navigation with online obstacle perception Non-Linear MPC

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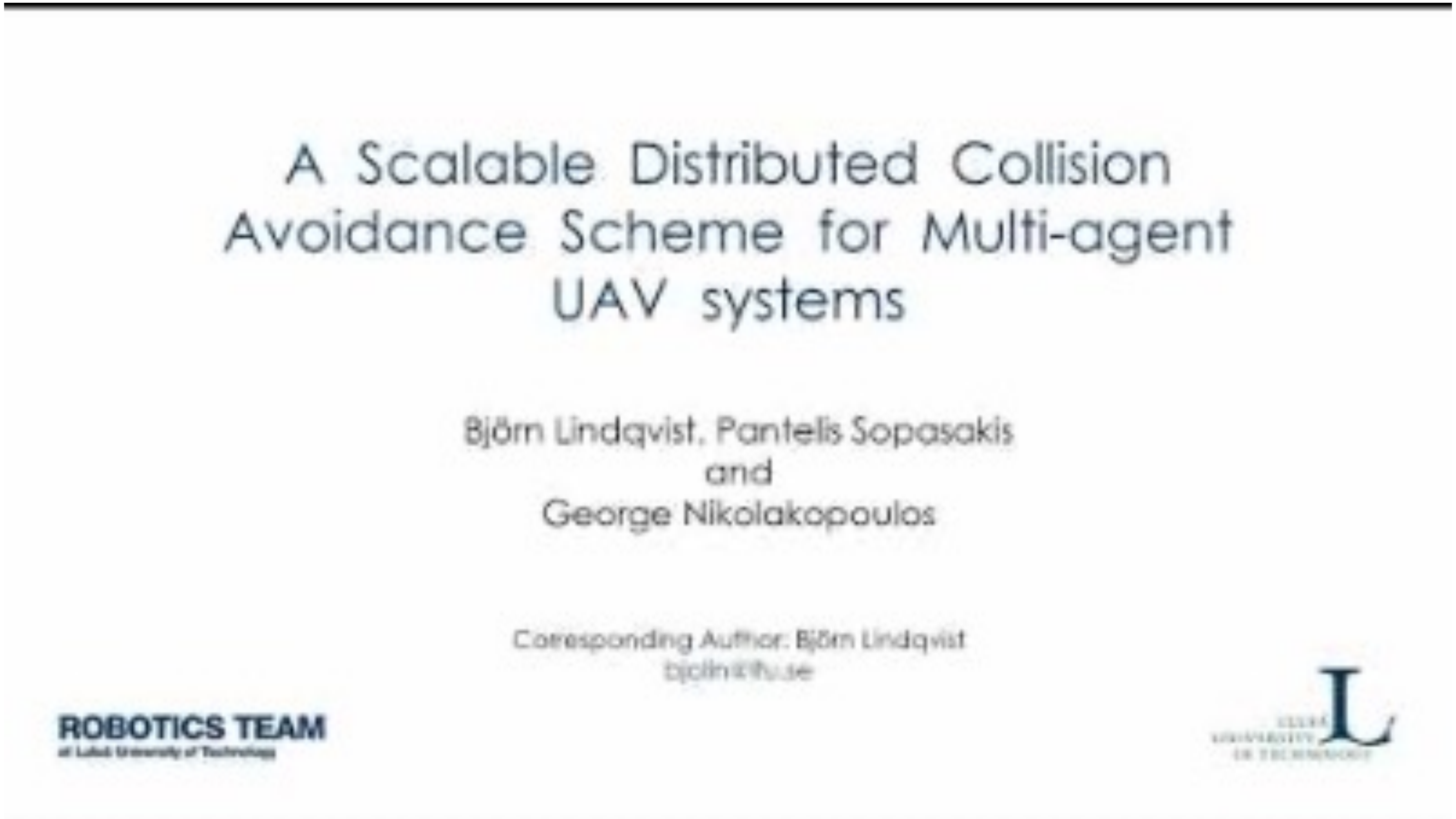
Reactive Distributed Collision Avoidance mor Multi UAVs



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On Unification
Hyper-Modality Robotic platforms

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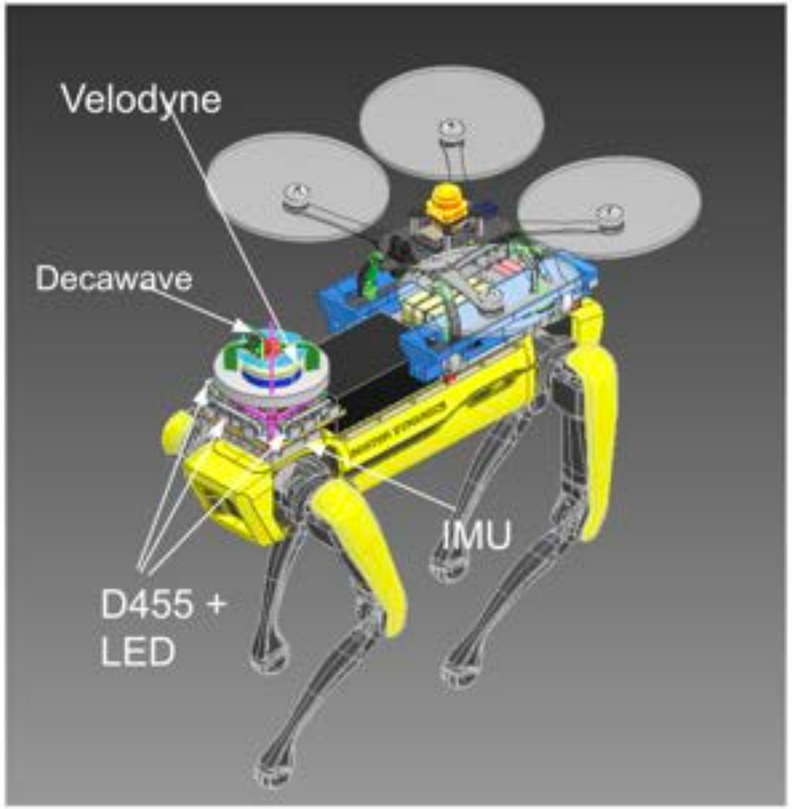
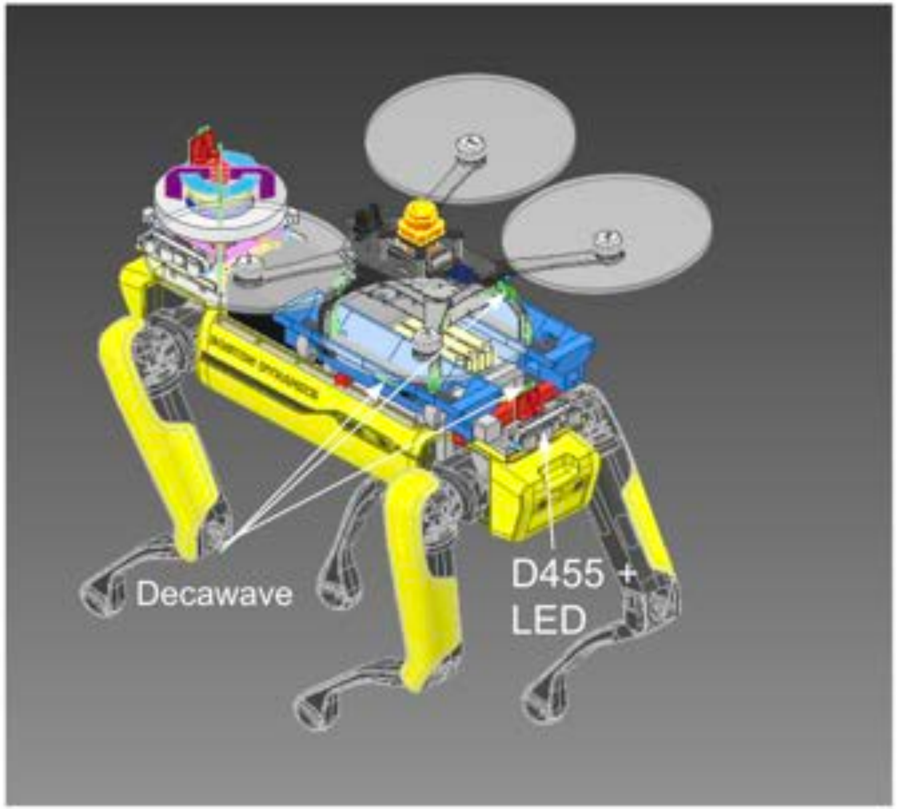
Our new Team Member

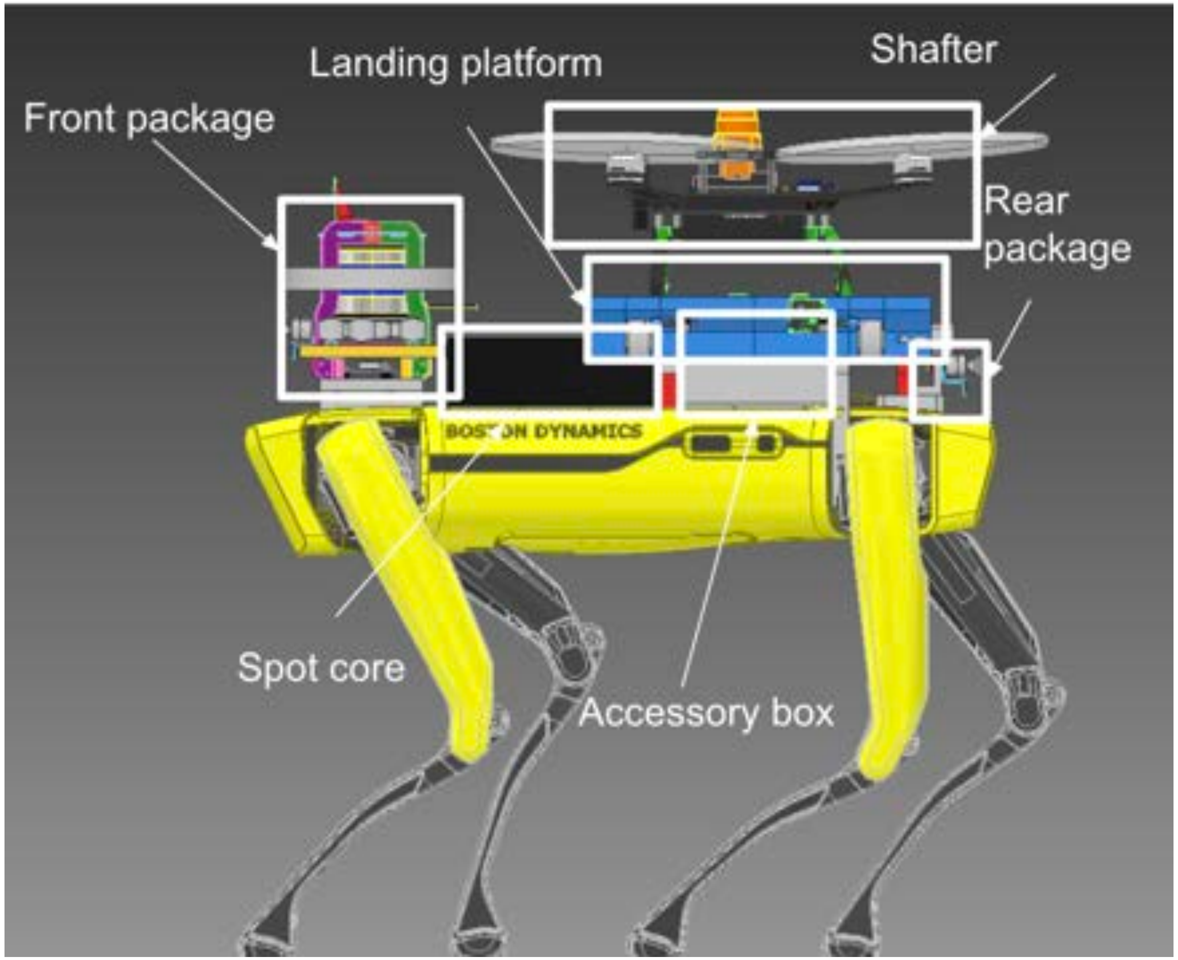
Hyper Modality Robotics

Hyper Modality Robotics

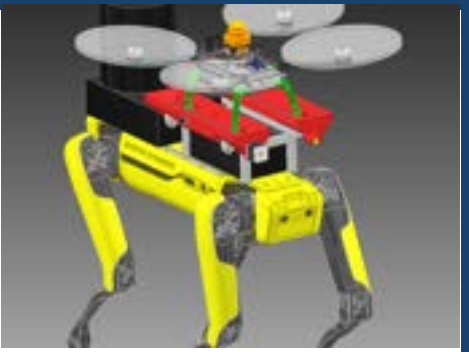


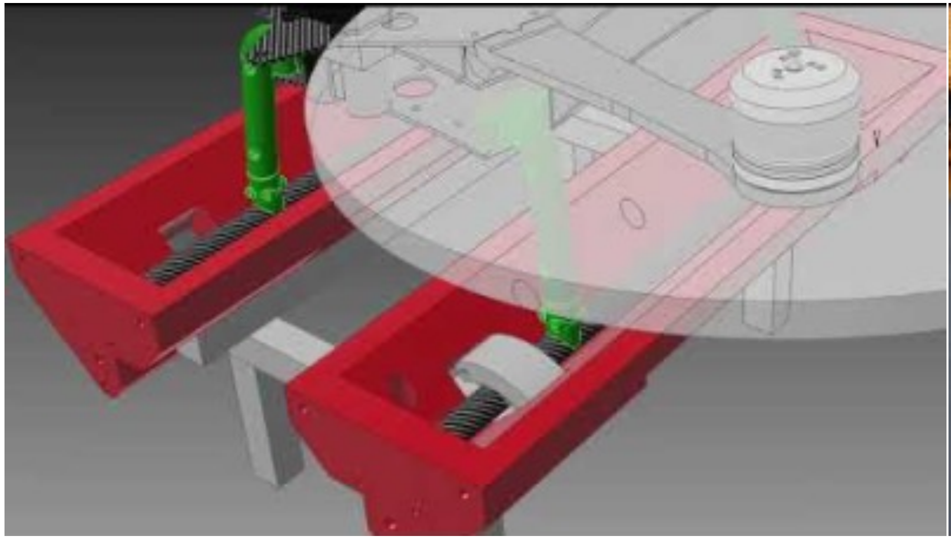


Hyper Modality Robotics



Hyper Modality Robotics





Hyper Modality Robotics in Caving environments

Relative Pose Estimation

Hyper Modality Robotics in Caving environments

Frontier Based Collaborative Exploration of planetary SubT environments

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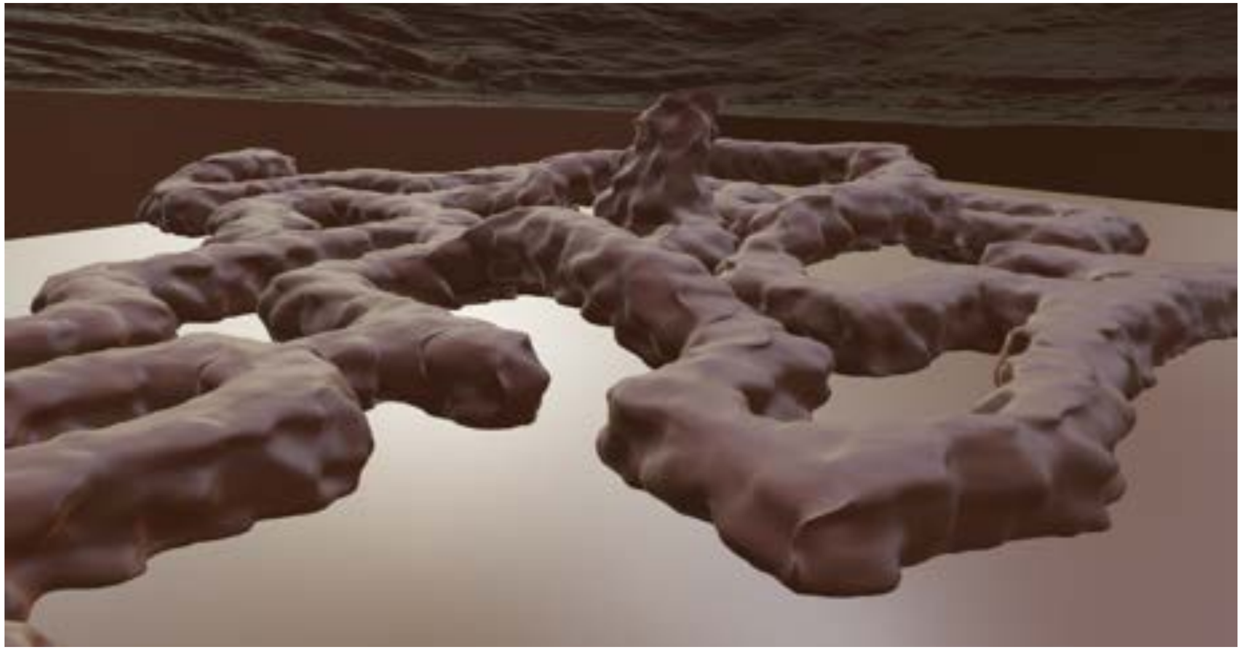
Exploration of potential lava tubes on Mars



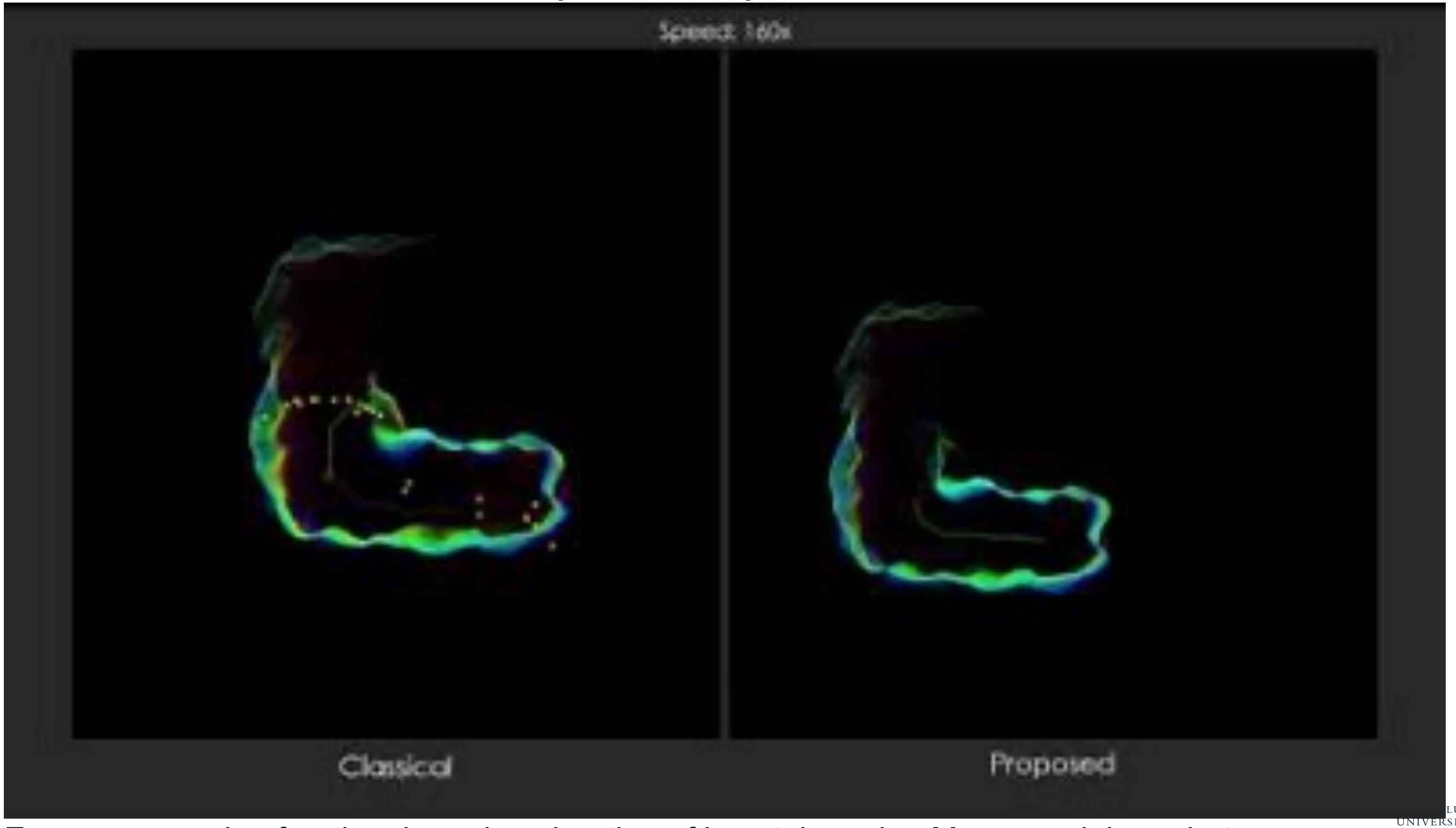
Lava tube like Gazebo environment for exploration beneath Mars surface

- Unstructured walls
- Steep slopes
- Narrow and wide passages
- Multiple junctions

Full Scale Realistic Autonomy Scenarios Simulation

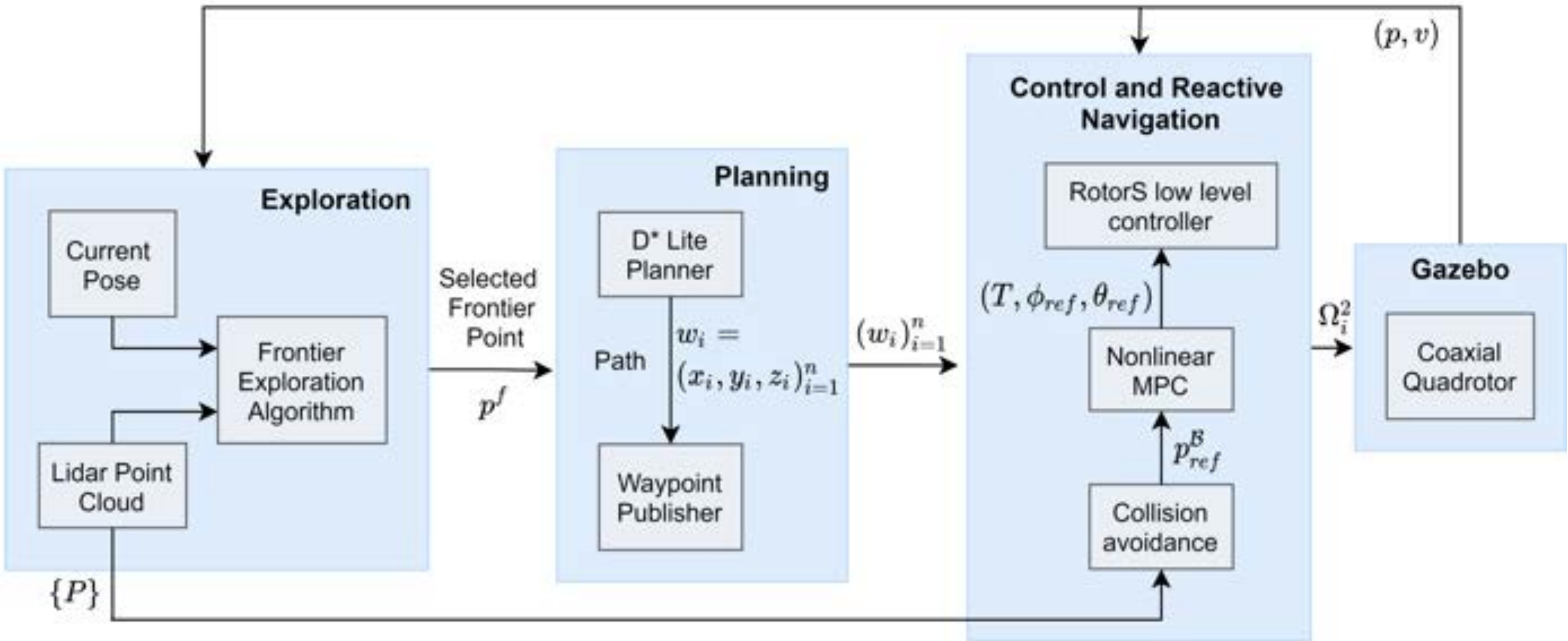
Mars Coaxial Quadrotor – Balloon Falling Tests

Frontier Based Exploration of potential lava tubes on Mars



Energy preserving frontiers based exploration of lava tube using Mars coaxial quadrotor

Exploration Autonomy Framework



Collaborative Exploration Autonomy Framework

The collaboration strategy is to split the agents apart when they share a certain common field of view.

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Space Autonomy for
Cooperative Satellite Inspection Missions

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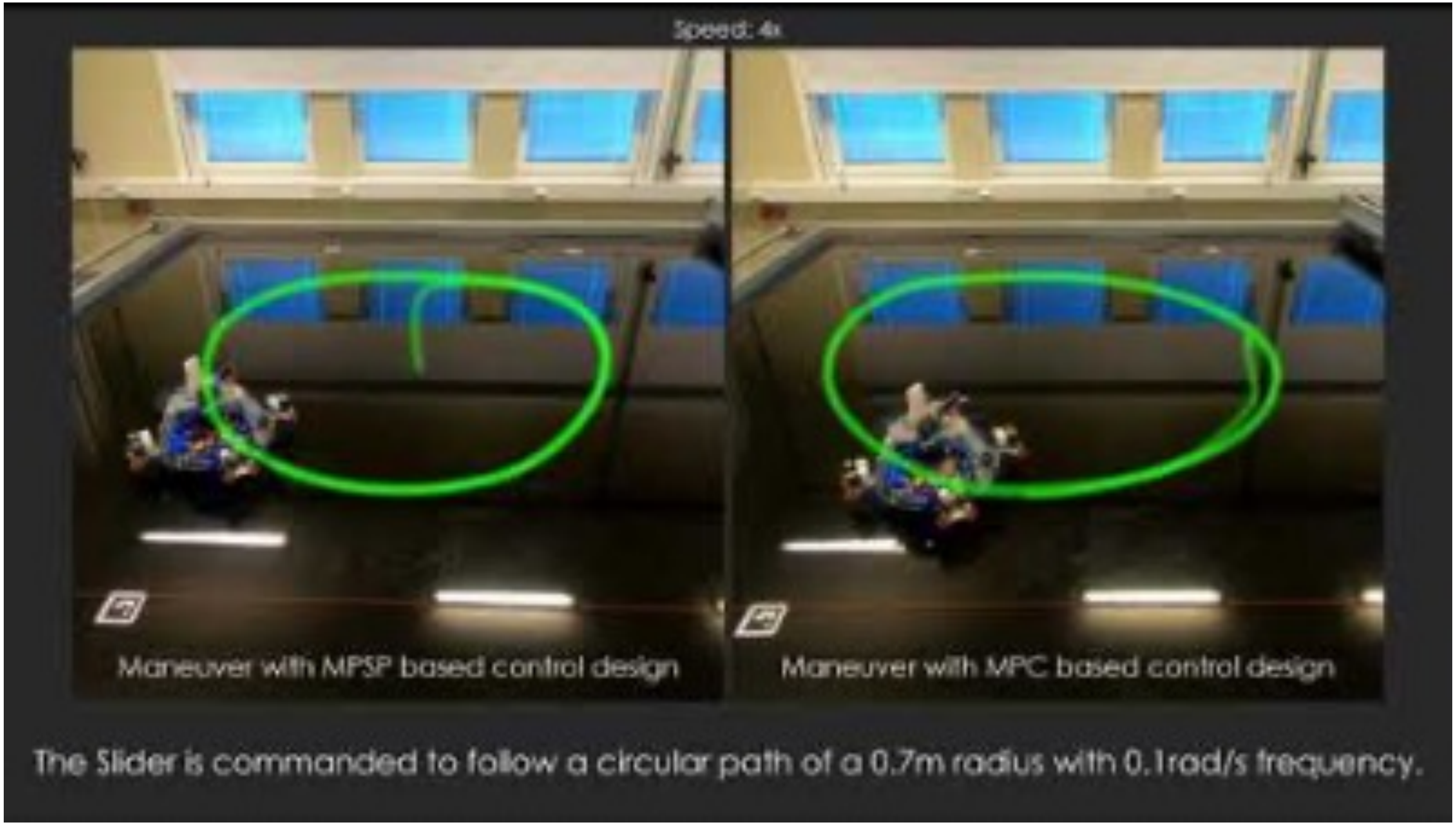
Autonomy for satellite navigation

MPSP for satellite navigation



SPACE ROS

- Feedback provided for Space ROS development
  - Technology gaps in areas of interest (e.g. surface and in-space systems)
- Currently ROSified field hardened robotics software

System/Mission Attributes	Comments / Description
Robotic Cardinality	Multi robot system
Operational Environment	Man-made caves, mines. Can be deployed in more areas.
Degree and Mode of Perception	3D Lidar, Stereo Vision (RGB-D), Odometry (IMU, SLAM).
Degree and Mode of Locomotion/Mobility	Legged, aerial, 2D-satellite.
Degree and Mode of Manipulation	None
Degree and Mode of Human Interaction	Full autonomy (human supervision for safety and some mission definition before starting)
Unique constraints and considerations	Legged robot carries aerial robot, where the aerial robot is being deployed to areas where the legged robot cannot reach.

Algorithms	GNC including motion planning (coverage planning, planar platform motion and docking), path planning (voxel map global planning), obstacle avoidance (artificial potential fields), exploration (frontiers, RRT based) and robot control (PID, model based); sensor fusion (ekf, pose-graphs, relative pose); perception (3d mapping, open3D, object detection); multi-robot coordination (e.g auction based); robot behavior manager (behavior trees); Graphical User Interface for mission management and monitoring

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Cooperative Visual Coverage of Small Bodies/Asteroids

Visual coverage of multiple sites on the asteroid surface

- Minimize the consumption of fuel
- Observe illuminated sites
- Multiple cubesat scaled spacecraft

Landmark sites information → **#Phase 1** Single target optimization problem → **#Phase 2** Multi-target multiple spacecraft optimal sequencing algorithm

Phase 1: Generate elementary trajectories

Phase 2: Generate optimal sequencing

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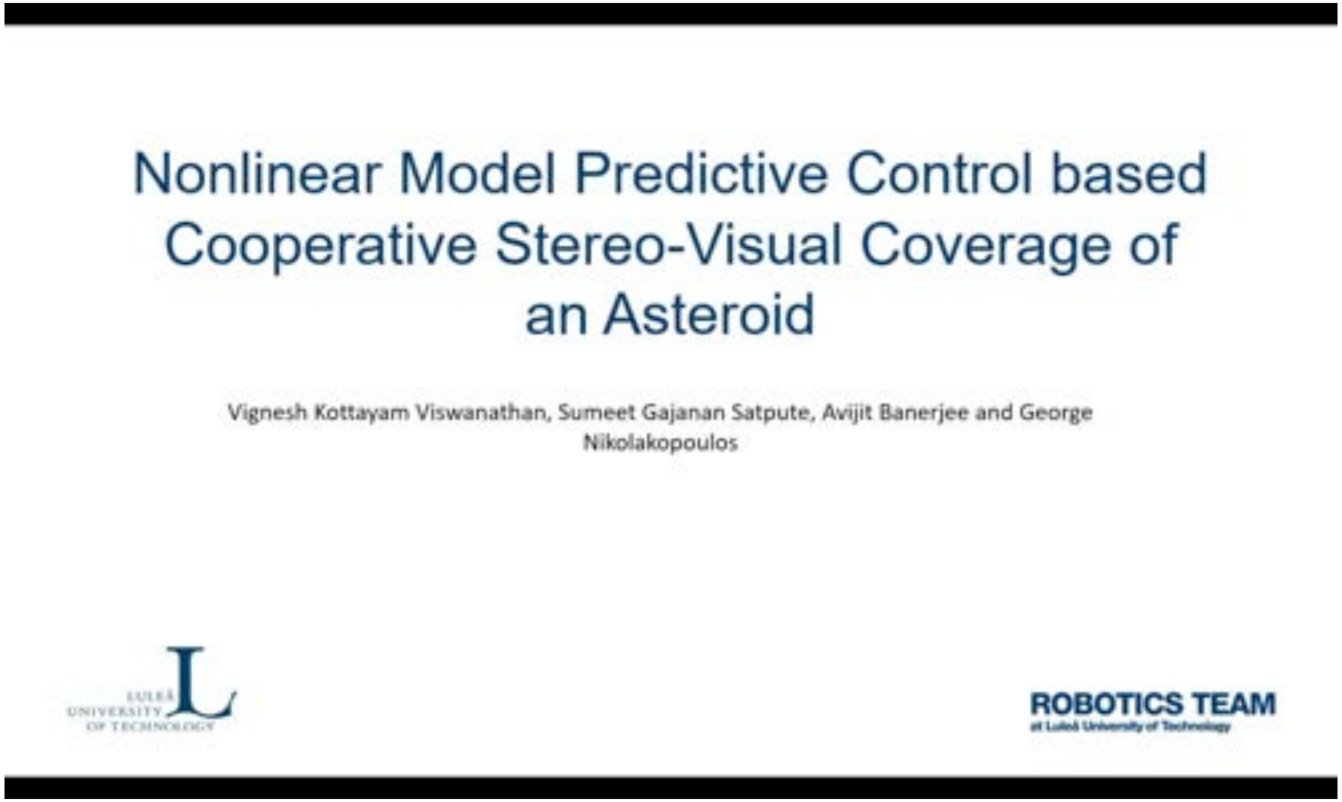
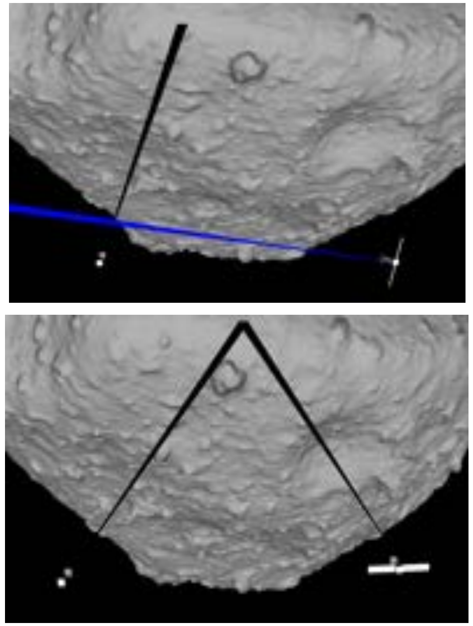
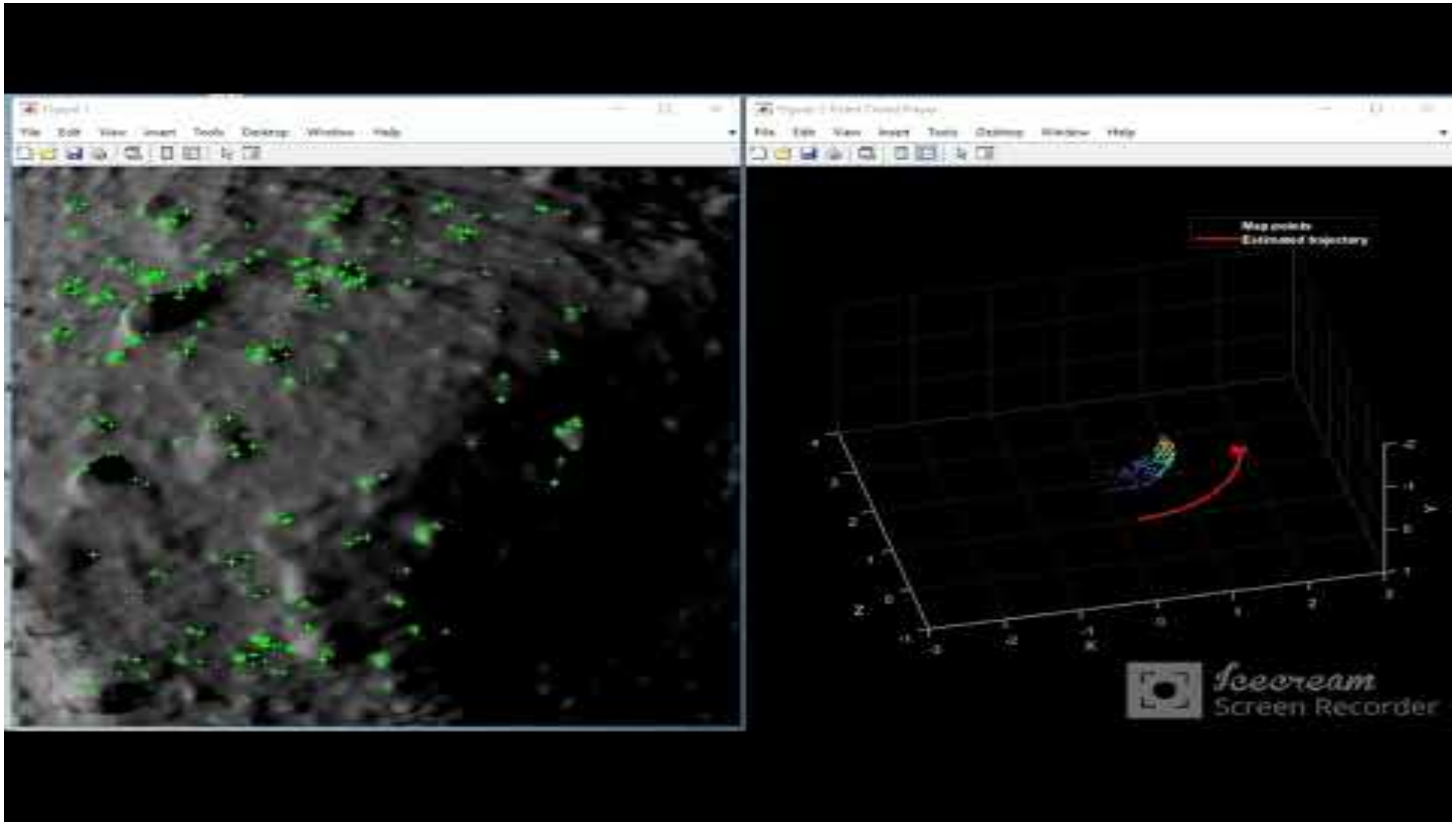
Cooperative Stereo-Visual Coverage of an Asteroid





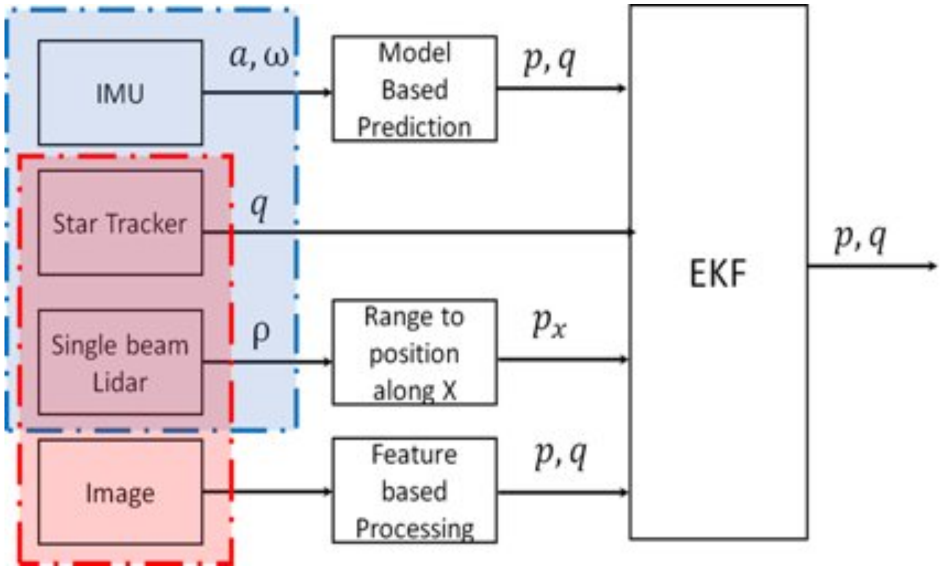
Cooperative stereo-visual coverage of Ryugu asteroid by implementing a *Leader-Follower* approach

Autonomous Navigation around Asteroid OHB

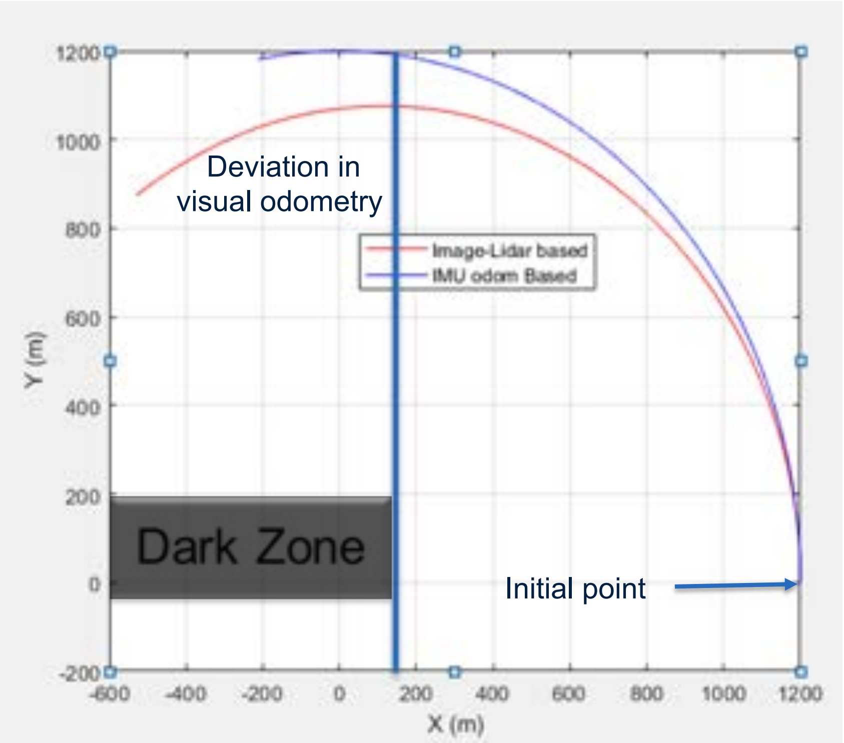


Demonstration of onboard perception based visual navigation around asteroid Ryugu

Autonomous Navigation around Asteroid



Gazebo assisted visual demonstration tool orchestrating multiple satellite motion with camera footprint



Localization around Asteroid (Ongoing work)

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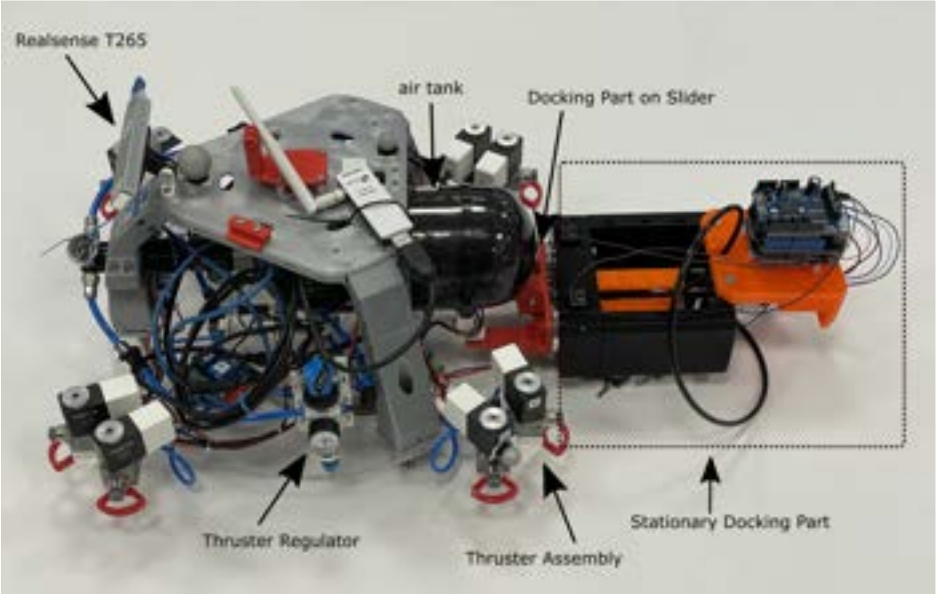
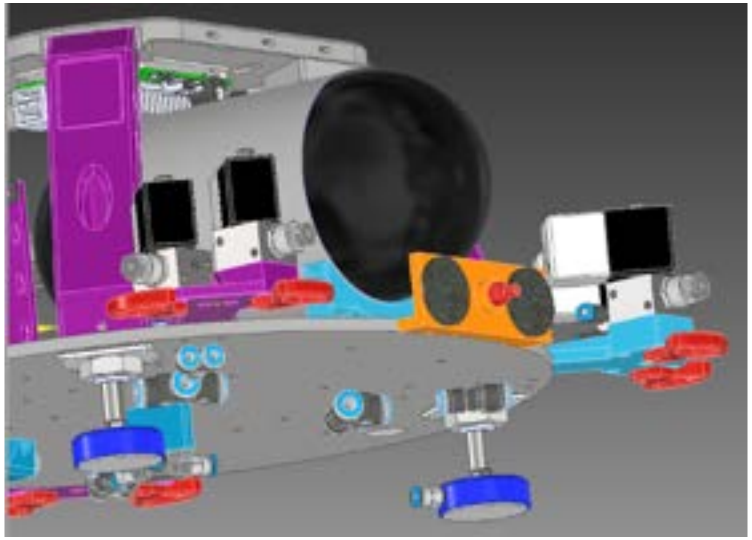
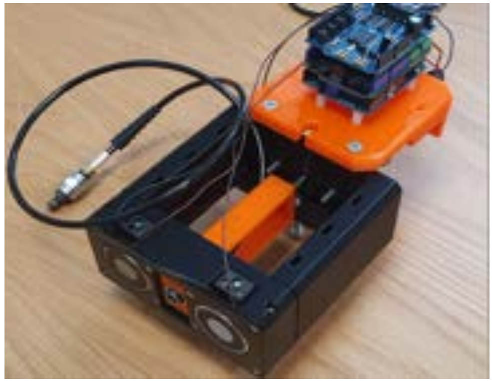
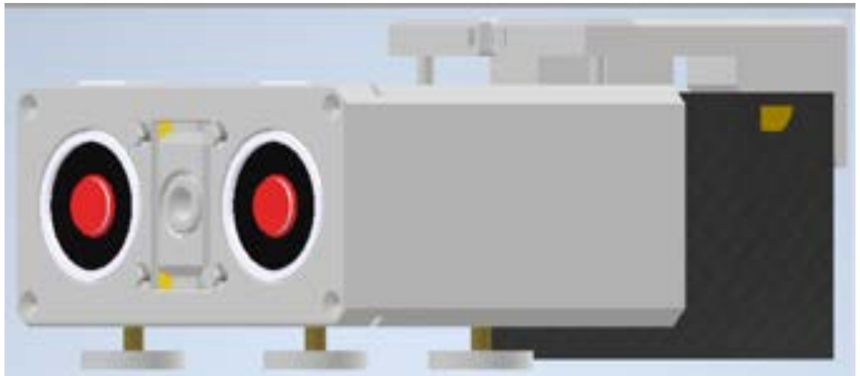
Concptual design





Electromagnetic actuator for stationary port





Stationary port

Thank you!

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