ELISA
Enabling Linux in Safety Applications

WORKSHOP

ELISA Workshop
Lund, Sweden

May 7-9, 2025

Co-hosted with Volvo Cars

ELISA
Enabling Linux in Safety Applications

WORKSHOP

PX4Space

Towards Open-source Space Robotics Facilities

Pedro Roque
Postdoctoral Researcher, PX4 Maintainer
Division of Decision and Control Systems
KTH Royal Institute of Technology
padr@kth.se , www.pedroroque.dev

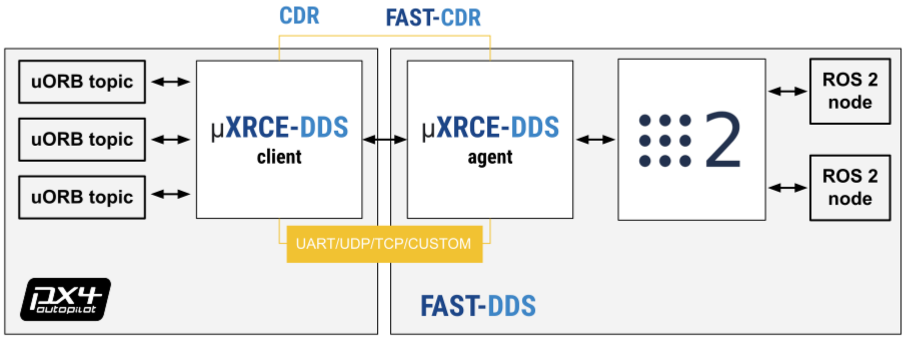
DISCOWER

WASP | WALLENBERG AI, AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM

Gentle Introduction to PX4 autopilot

Autonomy Stack originally developed for Aerial Robotics, primarily Multi Rotors, over time extended to support Fixed-Wing, VTOL, and Over & Under Surface Vehicles.

- Runs **realtime** on top of Apache NuttX RTOS
- **Modular** architecture with a **DDS-compatible middleware** (uORB)
- Modules are fully **parallelized**, and **thread safe**
- Native **ROS 2 Support** through DDS
- Great hardware support
- Support for custom builds, **remove modules that you don't need**



Pixhawk

ModalAI VOXL

Going to the moon! [1]

Gentle Introduction to PX4 autopilot

Autonomy Stack originally developed for Aerial Robotics, primarily Multi Rotors, over time extended to support Fixed-Wing, VTOL, and Over & Under Surface Vehicles.

- **Multi-Vehicle** type support:
  - **Multicopter, Fixed Wing, VTOL, Rover, Under Surface, Above Surface**
  - **Balloons, Satellites, Jetpack!**
- **Flight Modes** provide a set of helpers to control autonomy
- **Parameter** database exposing functionality back to users
- **Dronecode Ecosystem**

QGroundControl MAVSDK pixhawk
MAVLINK MICRO AIR VEHICLE COMMUNICATION PROTOCOL Auterion NXP OpenCV
THE LINUX FOUNDATION open source robotics alliance

ELISA Enabling Linux in Safety Applications WORKSHOP

Gentle Introduction to PX4 autopilot

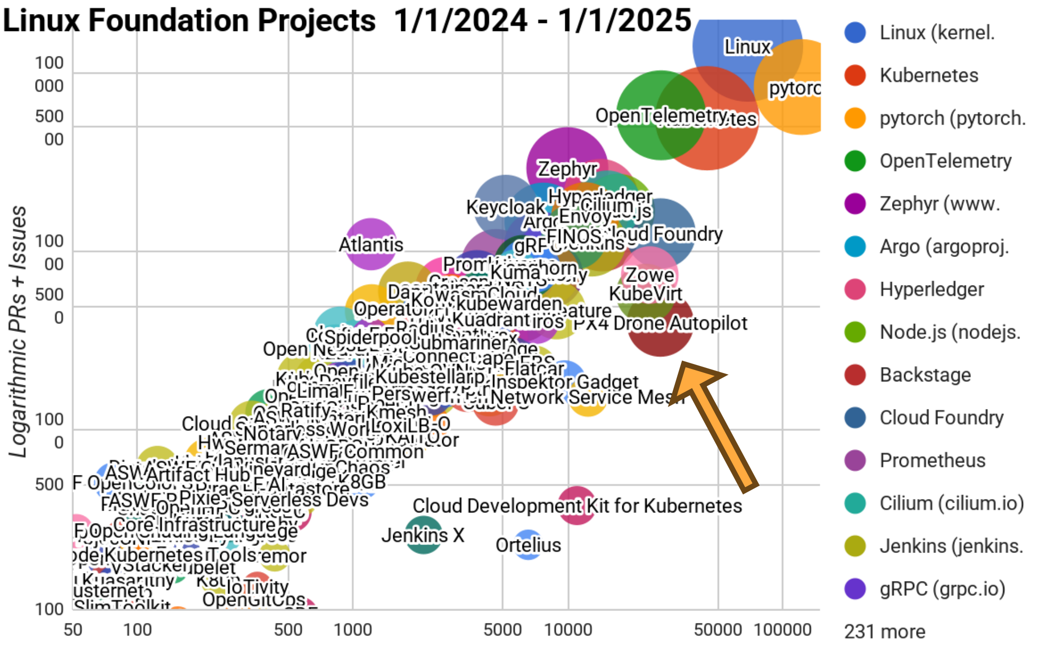
Autonomy Stack originally developed for Aerial Robotics, primarily Multi Rotors, over time extended to support Fixed-Wing, VTOL, and Over & Under Surface Vehicles.

- **Multi-Vehicle** type support:
  - **Multicopter, Fixed Wing, VTOL, Rover, Under Surface, Above Surface**
  - **Balloons, Satellites, Jetpack!**
- **Flight Modes** provide a set of helpers to control autonomy
- **Parameter** database exposing functionality back to users
- **Dronecode Ecosystem**
- Open **Source BSD-3 License**

Gentle Introduction to PX4 autopilot

Top LF Projects

1. **Linux**
2. Kubernetes
3. **pytorch**
4. OpenTelemetry
5. **Zephyr**
6. Argo
7. Hyperledger
8. Node.js
9. Backstage
10. Cloud Foundry
11. Prometheus
12. Cilium
13. Jenkins
14. **gRPC**
15. Envoy
16. **PX4 Drone Autopilot**
17. Meshery
18. FINOS
19. Keycloak
20. Crossplane



>13k contributors
>1,000,000 devices in the air

ELISA
Enabling Linux in Safety Applications

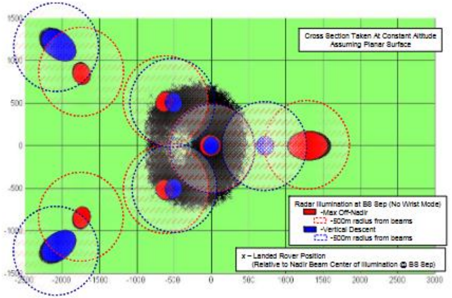
WORKSHOP

Great… but, Space Robotics?

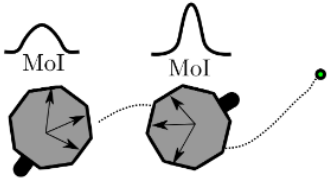
Motivation

From Algorithm to Space Deployment

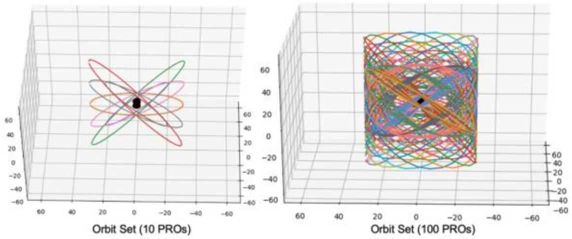
Algorithms
Control Planning
Estimation …



Radar illumination of the surface from backshell separation altitudes [2].



Path planning for information gain on disturbed spacecraft dynamics [3].



Passive relative orbits for spacecraft inspection tasks [4].

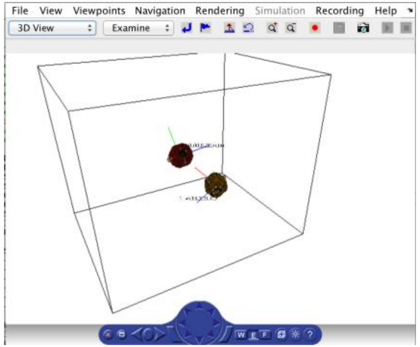
Motivation

From Algorithm to Space Deployment

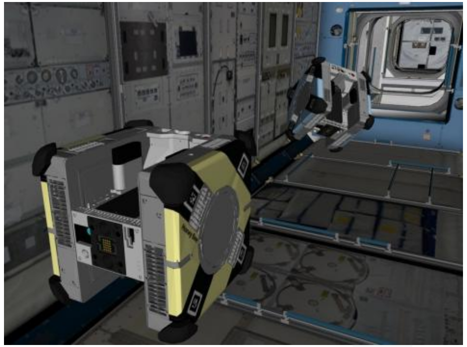
Algorithms
Control Planning
Estimation …

→

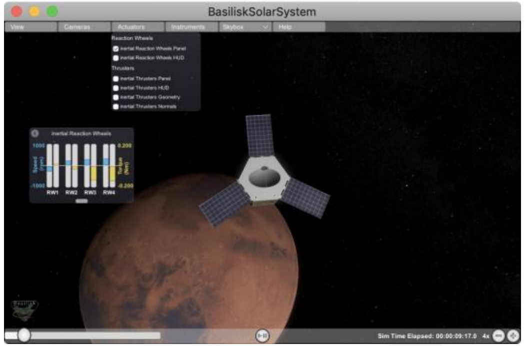
Simulation
Matlab, ROS, cFE
Basilisk, …



MIT SPHERES Matlab Simulation Environment with two robots. [5]



NASA Astrobee simulator, based on ROS and Gazebo. [6]



Basilisk's Vizard Unity-based simulation environment. [7]

Motivation

From Algorithm to Space Deployment

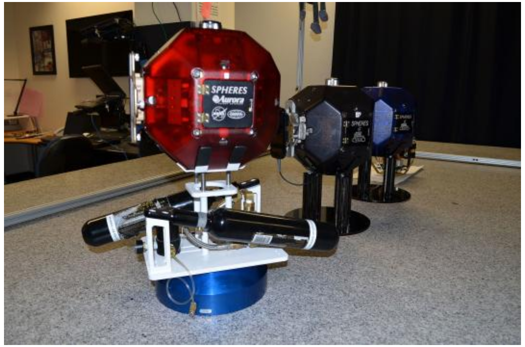
<u>*Algorithms*</u>
Control Planning
Estimation …

→

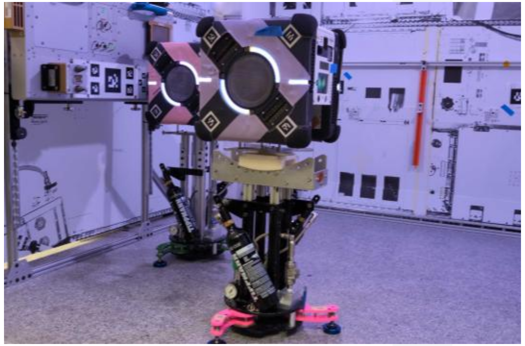
<u>*Simulation*</u>
Matlab, ROS, cFE
Basilisk, …

→

<u>*Analog Hardware*</u>
Ground-testing facilities
Free-flyer platforms



MIT Space Systems Laboratory with three SPHERES units. [5]



NASA Astrobee granite testbed facility at NASA Ames. [6]

Three CubeSat’s Hardware prototypes at CMU’s Robotic Exploration Lab. [8]

Motivation

From Algorithm to Space Deployment

Algorithms
Control Planning
Estimation …

→

Simulation
Matlab, ROS, cFE
Basilisk, …

→

Analog Hardware
Ground-testing facilities
Free-flyer platforms

→

Target
Satellite,
Autonomous Units

MIT SPHERES in the Space Station. [5]

NASA Astrobee robots performing a formation keeping maneuver. [9]

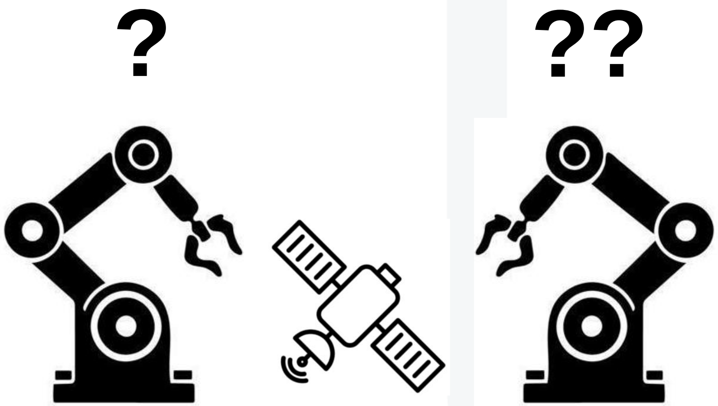
CubeSats being deployed in LEO orbit. [10]

Motivation

Flaws in the State-of-the-art

Drawbacks with current solutions:

1. Hard to replicate testbeds



Analog Hardware
Ground-testing facilities
Free-flyer platforms

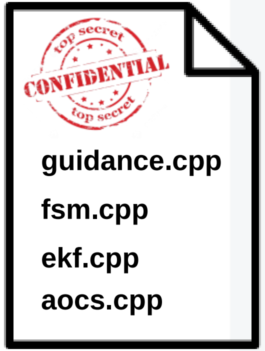
Motivation

Flaws in the State-of-the-art

Drawbacks with current solutions:

1. Hard to replicate testbeds
2. Closed-source software

Analog Hardware
Ground-testing facilities
Free-flyer platforms



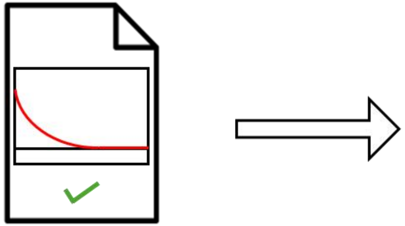
Motivation

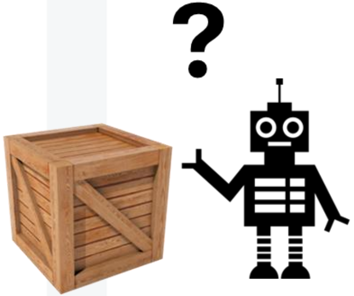
Flaws in the State-of-the-art

Drawbacks with current solutions:

Analog Hardware
Ground-testing facilities
Free-flyer platforms

1. Hard to replicate testbeds
2. Closed-source software
3. Hard to reproduce results





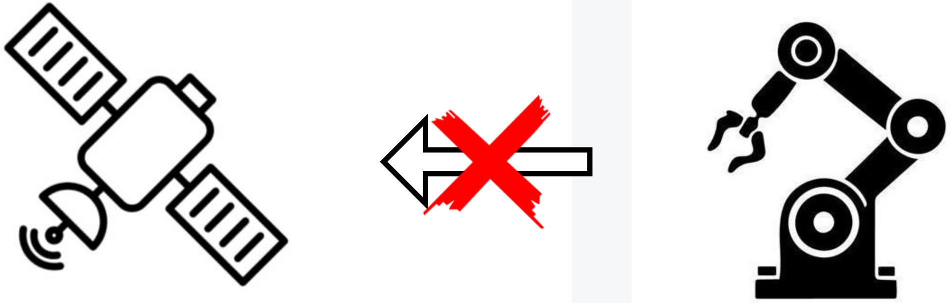
Motivation

Flaws in the State-of-the-art

Drawbacks with current solutions:

1. Hard to replicate testbeds
2. Closed-source software
3. Hard to reproduce results
4. Limited expandibility

Analog Hardware
Ground-testing facilities
Free-flyer platforms

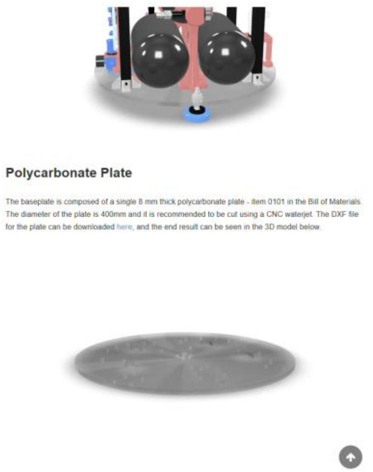


ELISA Enabling Linux in Safety Applications

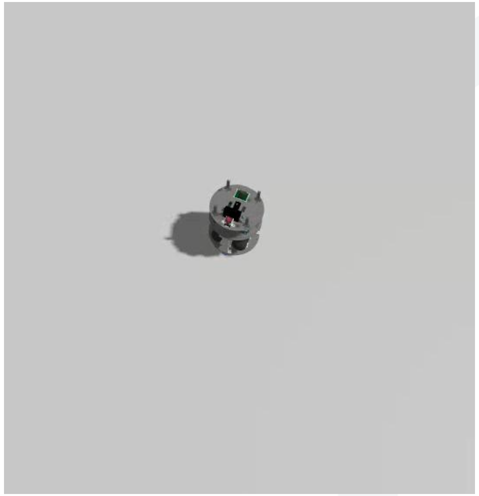
WORKSHOP

Meet PX4Space and ATMOS

Open-source as a Solution



Open-source Hardware
Step-by-step Guide

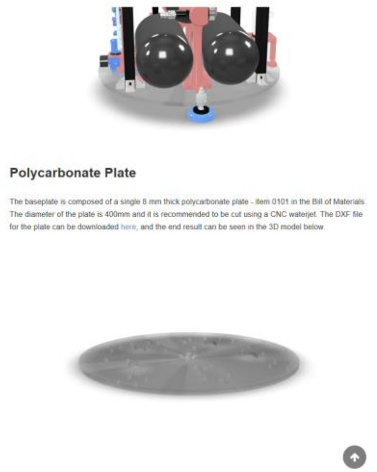


Open-source Software
SITL support

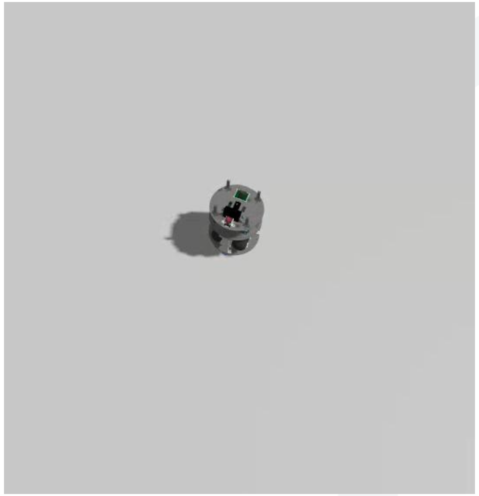
Low-cost
COTS Components [11]

Meet PX4Space and ATMOS

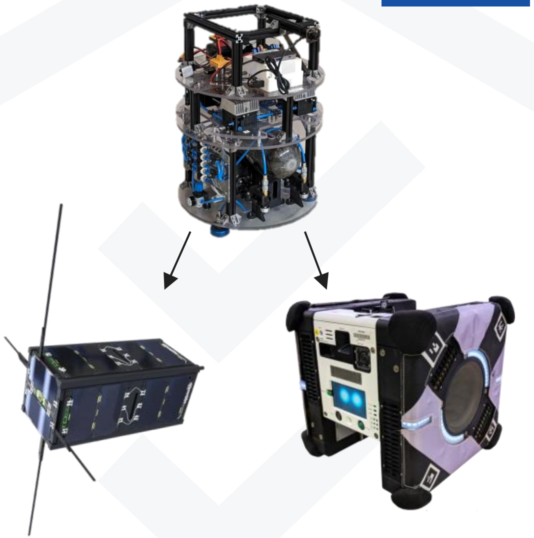
Open-source as a Solution



Open-source Hardware
Step-by-step Guide



Open-source Software
SITL support



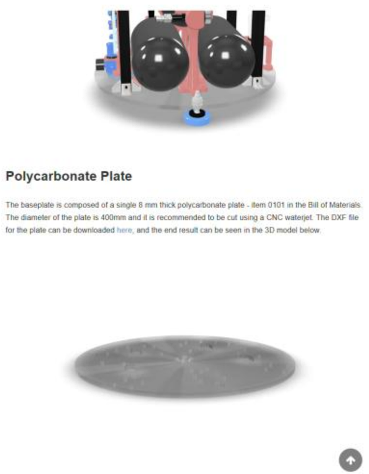
Analog for multiple Target systems
and autonomous facilities

ELISA Enabling Linux in Safety Applications

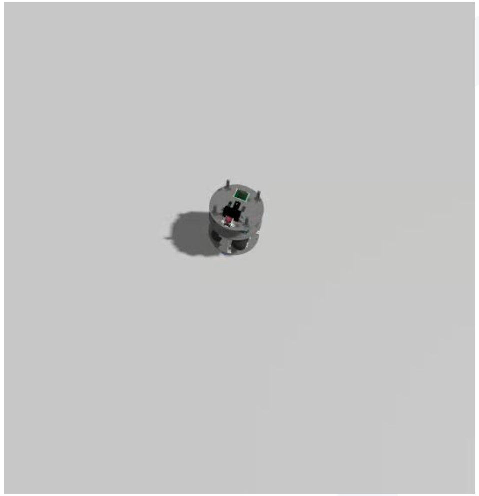
WORKSHOP

Meet PX4Space and ATMOS

Open-source as a Solution



Open-source Hardware
Step-by-step Guide



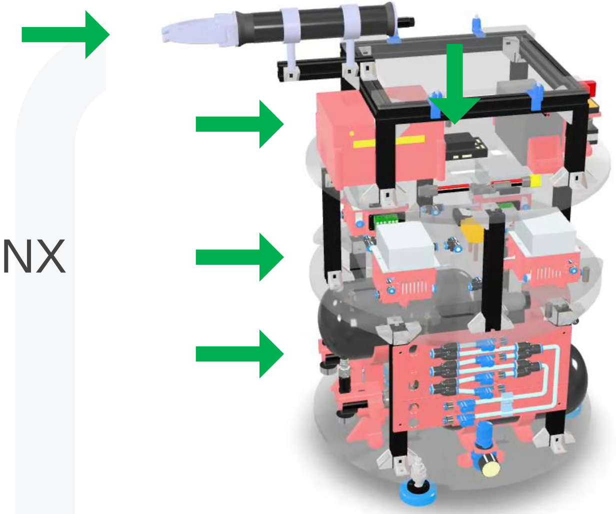
Open-source Software
SITL support

… not only microgravity facilities!

PX4Space, soon part of PX4-Autopilot

Overview of the Hardware

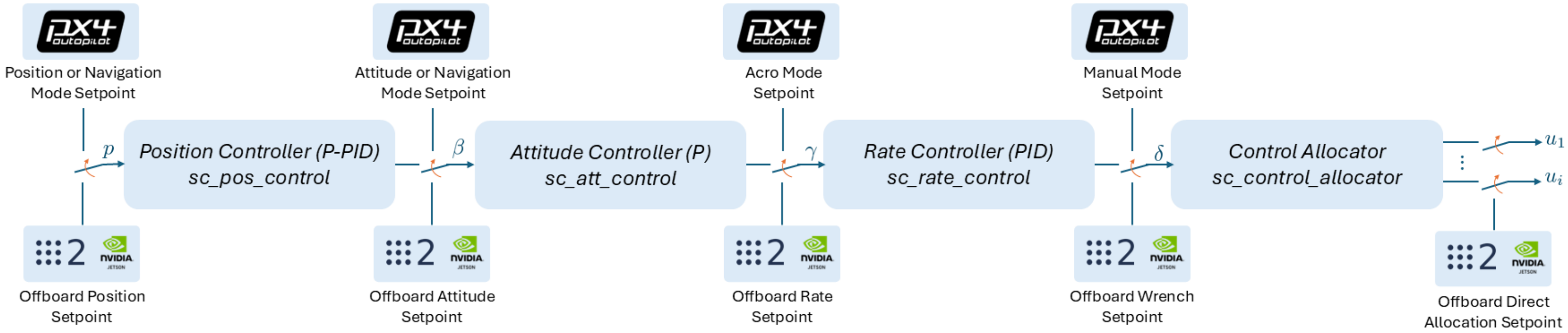
- Three 1.5 L , 300 bar air tanks
- Modular actuation plates:
  - Eight thrusters at 1.7 N (nominal)
  - Four bidirectional propellers at 1.95 N
- Onboard Computer – NVIDIA Jetson Orin NX
- Flight Controller: Pixhawk 6X Mini
- Payload Capabilities:
  - Grippers / Manipulators
  - Academic / Instrual Payloads, CubeSats, …



PX4Space, soon part of PX4-Autopilot

Overview of the Control Architecture

- On *PX4Space*:
  - Position and Attitude Setpoint
  - Force and Angular Rate Setpoint
  - Force and Torque Setpoint
  - Direct Actuator Control

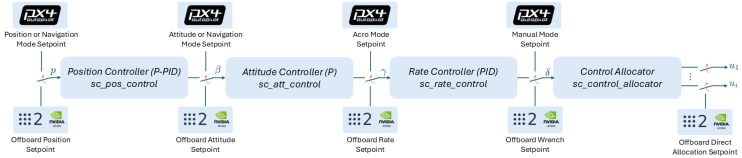


PX4Space, soon part of PX4-Autopilot

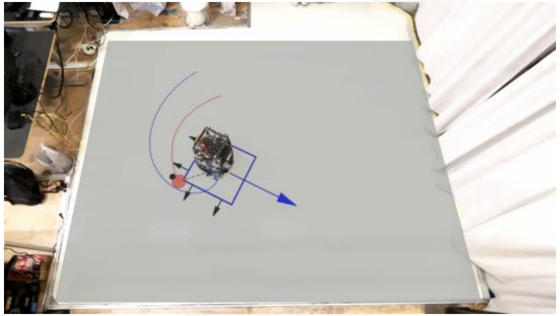
Overview of the Control Architecture

KTH VETENSKAP OCH KONST

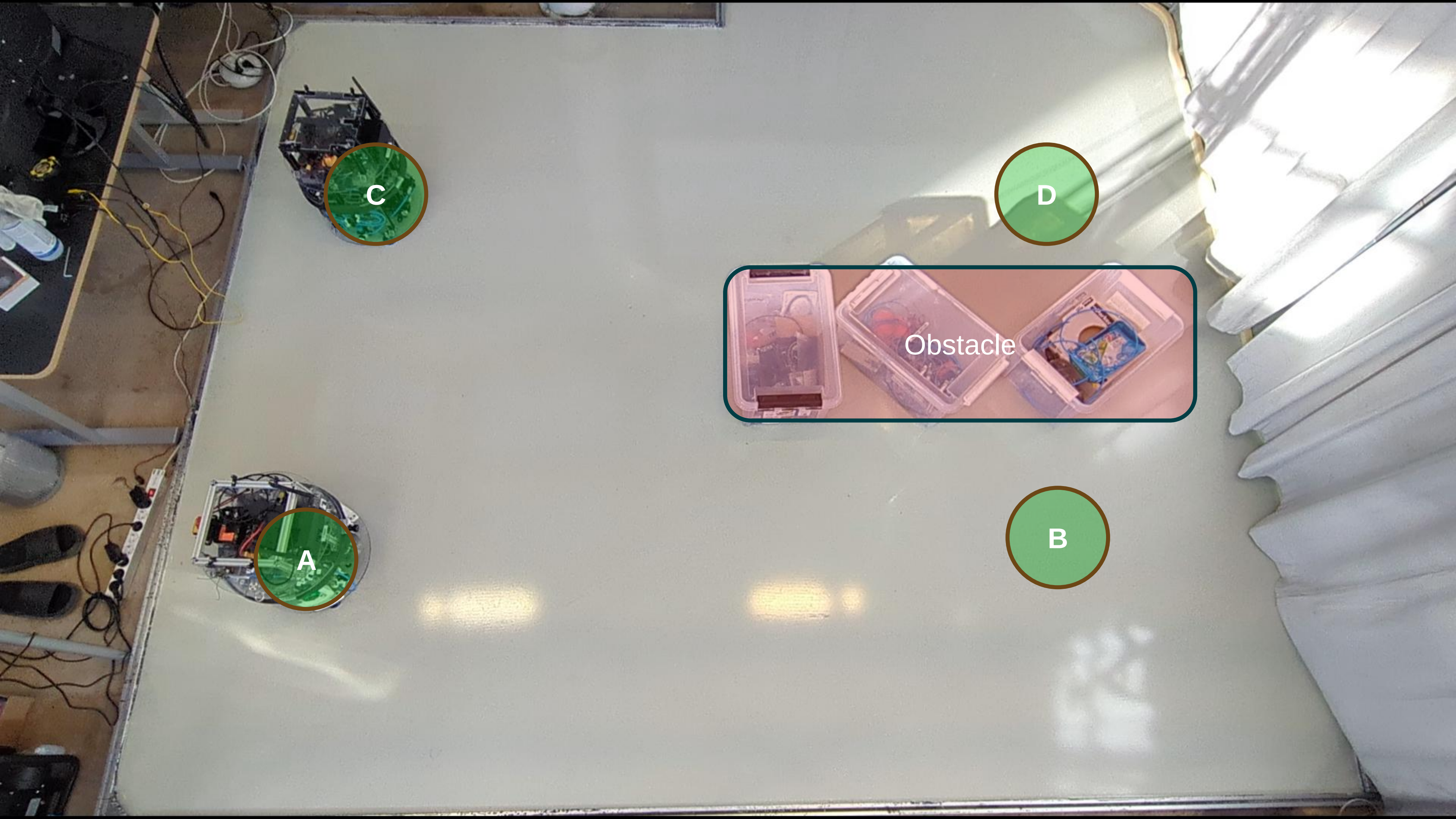
- On *PX4Space*:
  - Position and Attitude Setpoint
  - Force and Angular Rate Setpoint
  - Force and Torque Setpoint
  - Direct Actuator Control



- Onboard Computer:
  - Advanced Control Schemes (NMPC, …)
  - Advanced Planning Schemes (TL, Trees, …)
  - OS and Middlewares (F’, SGL, Space ROS?)



Fault-Tolerant Model Predictive Control for Spacecraft [12].


C
D
Obstacle
A
B

The Team


Christer Fuglesang


Ivan Stenius


Jana Tumova


Gunnar Tibert


Roland Siegwart


Huina Mao


Dimos Dimarogonas


Elias Krantz


David Dorner


Chelsea Sidrane


Matti Vahs


Jaeyoung Lim


Joris Verhagen


Pedro Roque


Sujet Phodapol


Tafarrel Pramono


Frank Jiang


Raphael Stöckner

The Team

Christer Fuglesang | Ivan Stenius | Jana Tumova | Gunnar Tibert | Roland Siegwart | Huina Mao | Dimos Dimarogonas

Elias Krantz | David Dorner | Chelsea Sidrane | Matti Vahs | Jaeyoung Lim | Joris Verhagen | Pedro Roque | Sujet Phodapol | Tafarrel Pramono | Frank Jiang | Raphael Stöckner

px4 autopilot

Community

ELISA Enabling Linux in Safety Applications

WORKSHOP

Challenges

ELISA
Enabling Linux in Safety Applications

WORKSHOP

How can Linux bridge certifiable Academic and Industrial development?

ELISA
Enabling Linux in Safety Applications

WORKSHOP

What is really important to certify?

ELISA
Enabling Linux in Safety Applications

WORKSHOP

ELISA
Enabling Linux in Safety Applications

WORKSHOP

PX4Space

Towards Open-source Space Robotics Facilities

atmos.DISCOWER.io

Pedro Roque, padr@kth.se, www.pedroroque.dev

ELISA
Enabling Linux in Safety Applications

WORKSHOP

PX4Space

Towards Open-source Space Robotics Facilities

github.com/DISCOWER

Pedro Roque, padr@kth.se, www.pedroroque.dev

References

[1] Saboia, M., Rossi, F., Nguyen, V., Lim, G., Aguilar, D., & de la Croix, J. P. (2024). CADRE MoonDB: Distributed Database for Multi-Robot Information-Sharing and Map-Merging for Lunar Exploration. In Proc. Int. Conf. on Autonomous Agents and Multiagent Systems.

[2] Prakash, R., Burkhart, P. D., Chen, A., Comeaux, K. A., Guernsey, C. S., Kipp, D. M., ... & Way, D. W. (2008, March). Mars science laboratory entry, descent, and landing system overview. In 2008 IEEE Aerospace Conference (pp. 1-18). IEEE.

[3] Albee, K., Ekal, M., Ventura, R., & Linares, R. (2019). Combining parameter identification and trajectory optimization: Real-time planning for information gain. arXiv preprint arXiv:1906.02758.

[4] Choi, C., Nakka, Y. K., Rahmani, A., & Chung, S. J. (2023, March). Resilient Multi-Agent Collaborative Spacecraft Inspection. In 2023 IEEE Aerospace Conference (pp. 1-10). IEEE.

[5] Miller, D., Saenz-Otero, A., Wertz, J., Chen, A., Berkowski, G., Brodel, C., ... & Sell, S. (2000, January). SPHERES: a testbed for long duration satellite formation flying in micro-gravity conditions. In Proceedings of the AAS/AIAA space flight mechanics meeting (Vol. 105, pp. 167-179). Clearwater, Florida, January.

References

[6] Fluckiger, L., Browne, K., Coltin, B., Fusco, J., Morse, T., & Symington, A. (2018, June). Astrobee robot software: A modern software system for space. In iSAIRAS (International Symposium on Artificial Intelligence, Robotics and Automation in Space) (No. ARC-E-DAA-TN55483).

[7] Kenneally, P. W., Piggott, S., & Schaub, H. (2020). Basilisk: A flexible, scalable and modular astrodynamics simulation framework. Journal of aerospace information systems, 17(9), 496-507.

[8] Available online at https://www.ri.cmu.edu/nasa-mission-to-test-technology-for-satellite-swarms-carnegie-mellons-zac-manchester-leads-three-satellite-experiment/ , on May 8th, 2025.

[9] Roque, P., Heshmati-Alamdari, S., Nikou, A., & Dimarogonas, D. V. (2020). Decentralized formation control for multiple quadrotors under unidirectional communication constraints. IFAC-PapersOnLine, 53(2), 3156-3161.

[10] European Space Agency: https://www.esa.int/ESA_Multimedia/Images/2020/02/CubeSat_deployment_from_ISS

References

[11] Roque, P., Phodapol, S., Krantz, E., Lim, J., Verhagen, J., Jiang, F. J., ... & Dimarogonas, D. V. (2025). Towards Open-Source and Modular Space Systems with ATMOS. Submitted to IEEE-TFR, Special Issue on Space Robotics.

[12] Stockner, R., Roque, P. & Dimarogonas, D. V. (2025). Fault-Tolerant Model Predictive Control for Spacecraft. Submitted to IEEE CDC 2025.

CubeSat (Slides 16-17): https://www.cubesatshop.com/helpful-links/about-cubesats/

Mars Rover – Curiosity (Slide 17): https://www.jpl.nasa.gov/missions/mars-science-laboratory-curiosity-rover-msl/

Lunar Lander (Slide 17): https://discoverspace.org/artifacts/lunar-module/

ELISA Enabling Linux in Safety Applications

WORKSHOP

PX4Space

Towards Open-source Space Robotics Facilities

Pedro Roque
Postdoctoral Researcher, PX4 Maintainer
Division of Decision and Control Systems
KTH Royal Institute of Technology
padr@kth.se , www.pedroroque.dev

DISCOWER

WASP WALLENBERG AI, AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM