Experimental Verification of Robotic Landing and Locomotion on Asteroids

University of Luxembourg

Interdisciplinary Centre for
Security, Reliability and Trust

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Agenda

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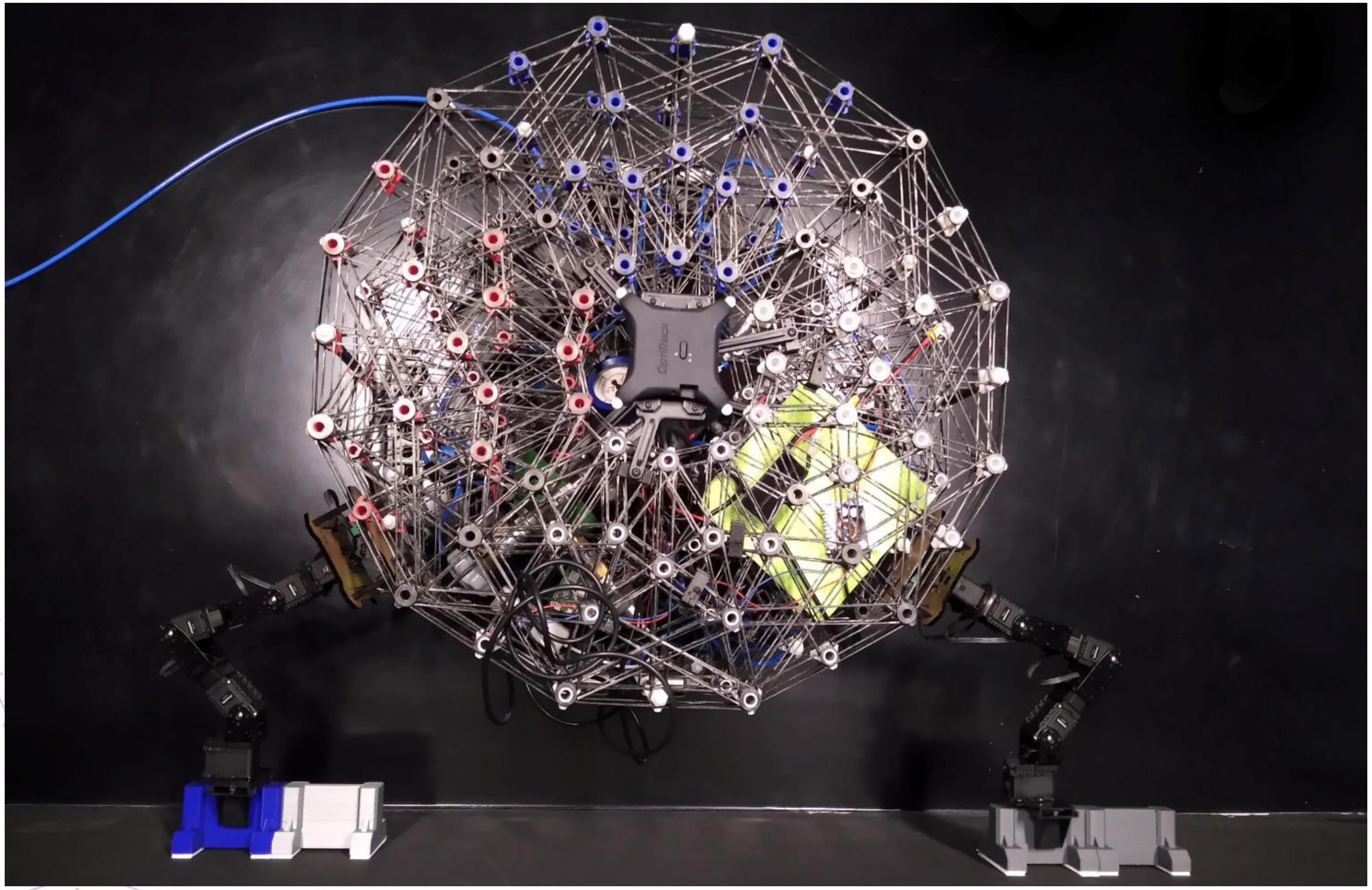
5. **Conclusion**



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1. Introduction

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Introduction

- In-situ explorations of asteroids and other small celestial bodies are crucial to collect surface samples, which could be the key to understanding the formation of our solar system.
- Studying the composition of asteroids is also important for future planetary defense and mining resources for in-situ utilization.
- However, the weak gravitational field poses many challenges for robotic landing and locomotion scenarios on the surface of asteroids.
- Emulators are needed to realize these scenarios.
- These emulations need to be tested, verified and validated in an on-ground facility.

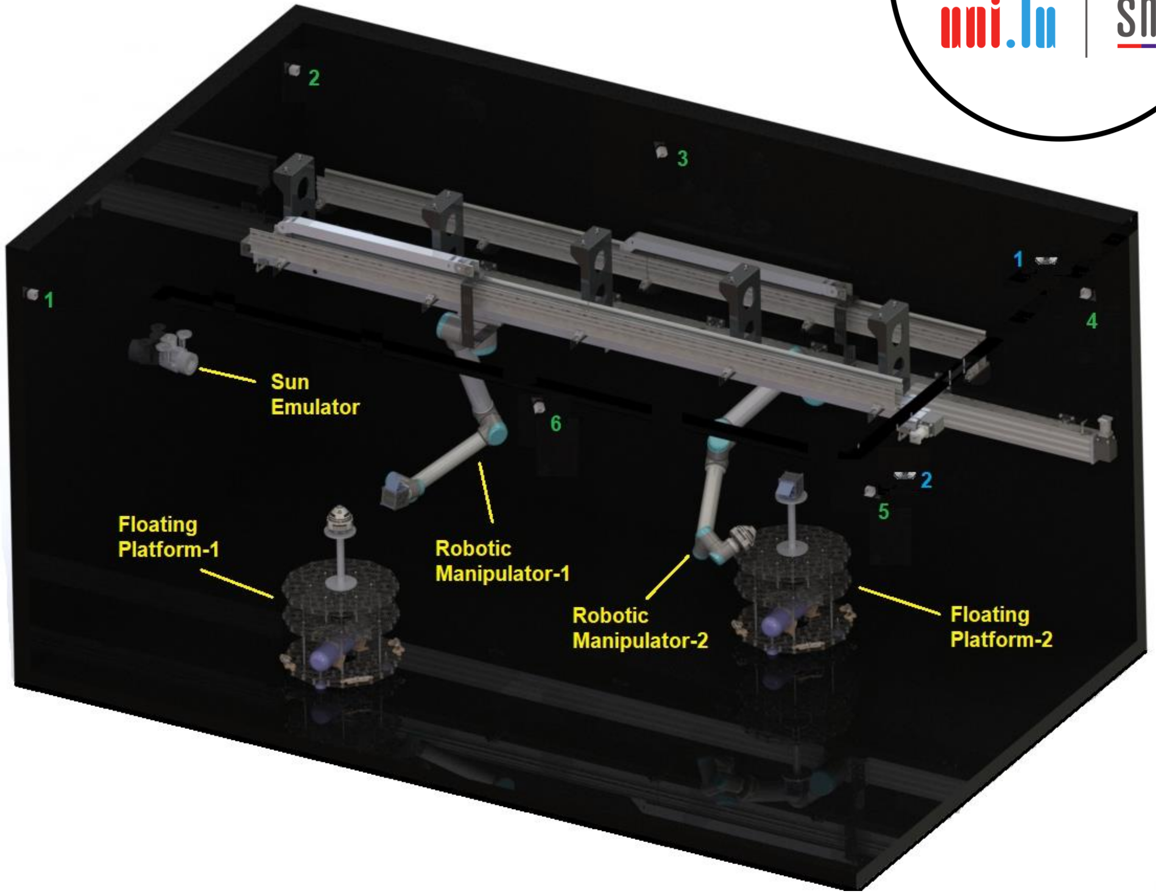

Fig. 1: Render of the Zero-G Lab

Introduction

- Zero-G Lab is designed to allow students and researchers to test the movement of in-orbit robotics, satellites and other spacecraft in a micro-gravity environment – similar in concept to an air hockey platform.
- On Earth, we take gravity for granted, but moving in its absence presents a number of challenges for in-orbit operations. For instance, a small push between two orbiting systems could make one or both to tumble and get out of control.
- Seeing how spacecraft and orbital robotics can be controlled or perform with decoupled systems in this environment provides students the unique chance of understanding and forecasting their behaviour in space.

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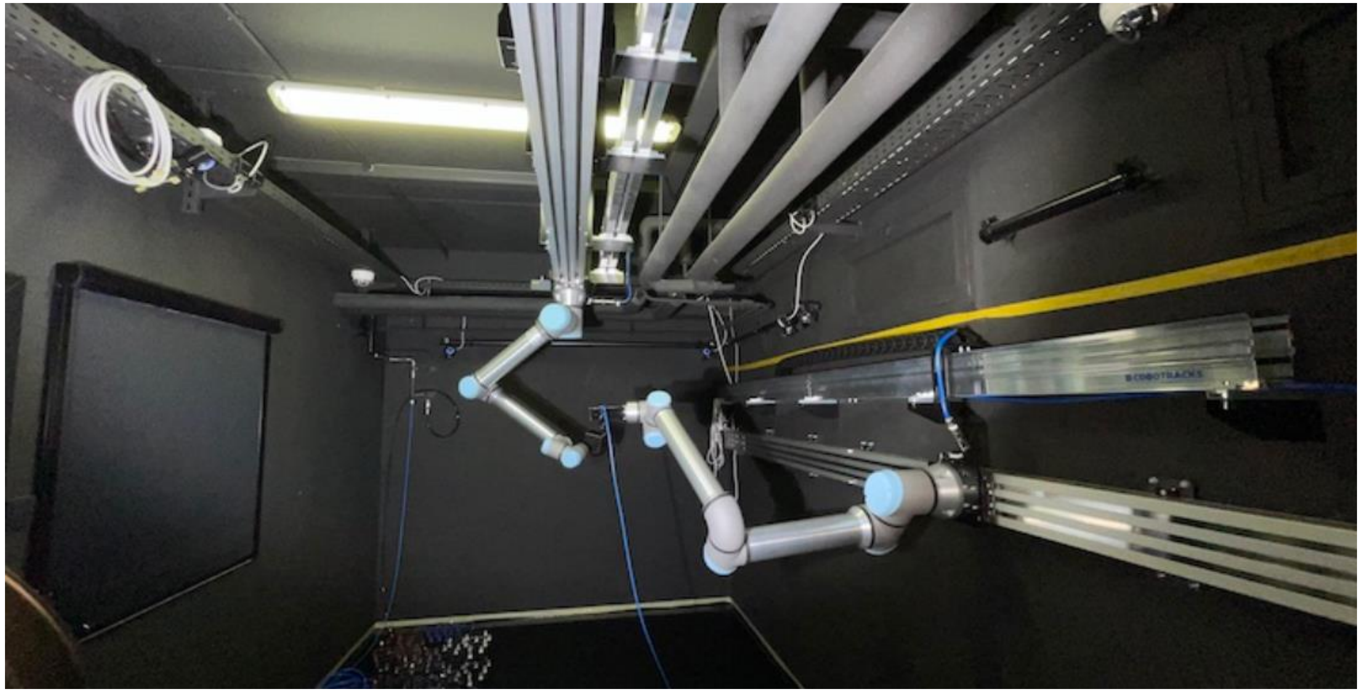

Fig. 2: The Zero-G Lab

Introduction

- Legged climbing robots are expected to perform well under microgravity, as they can maintain surface attachment, preventing undesired flotation and uncontrolled bouncing.
- Therefore, we need to consider methods to plan and control the landing and locomotion of climbing robots on asteroids.

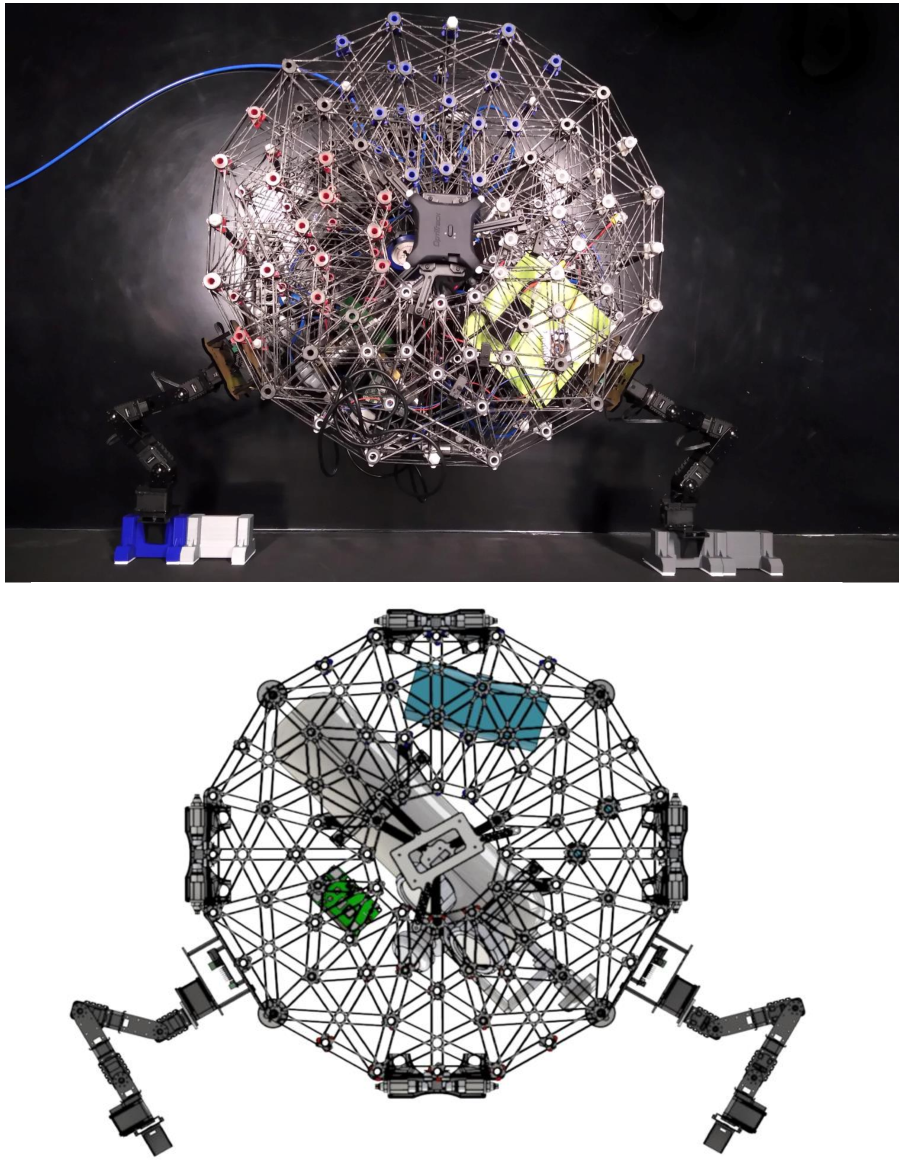

Fig. 3: Floating platform integrated with the robots as legs.

Introduction

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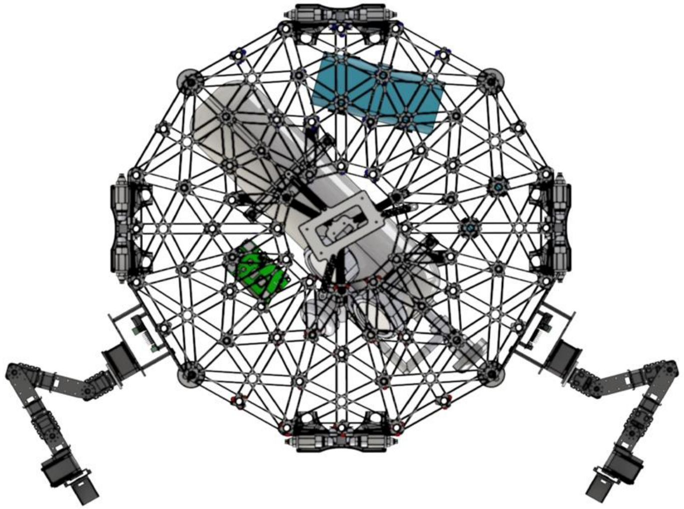
The national patent application in Luxembourg named “Pneumatic floating systems for performing zero-gravity experiments” has been filed and it is still under evaluation process, the patent application file number is LU503146.



Introduction

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- In this study, we have performed experiments regarding the emulation of two scenarios; 1- Landing, 2- Locomotion.
- For both landing and locomotion scenarios, separate PD controllers have been utilized.
- As position feedback, Motion Capture System (MCS) of Zero-G Lab is utilized.
- Landing emulation is a relatively new area, that is why we started using classical controllers, and then we can proceed with the advance ones (MPC etc)

Introduction/Specs

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- Total weight of the floating platform is 10.95 kg.
- It has four air-bearings and eight nozzles.
- The robotics arms (Pincher Robot Arm Kit) are used for locomotion (total two) and their drivers are assembled on both sides of the floating platform.
- Each robotic arm has five Degrees of Freedom (DoF) consisting of servo motors, including its gripper.

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2. Landing

Landing

- For the experimental emulation of the landing scenario, we assume our robotic platform with air thrusters to control the position and attitude necessary to achieve landing on an asteroid.
- A PD controller is used to realize the motion control of the floating platform, using the Ziegler–Nichols method as a heuristic method of tuning PD parameters. The tuning is utilized to minimize over-shoot and rise-time.

Landing

- D parameter of the PD controller is merged with the low-pass filter to suppress unexpected peaks in the feedback data.
- MCS uses sensory feedback at a frequency of 240 Hz
  for the closed loop, employing the extended Kalman Filter to deal with the noise in the MCS data.
- Since the floating platform has 3-DoF, a separate controller is assigned for each DoF.
- The landing and locomotion scenarios are sequential, therefore the locomotion operations begin after the landing is securely achieved.

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3. Locomotion

Locomotion

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- Experimental evaluation of locomotion is made using the same floating platform, with two robotic arms with grippers to emulate the climbing motion in two dimensions.
- The robot can achieve continuous mobility by moving each robotic arm to grasp the next target on the emulated surface, followed by the arms’ movement to drag the main body forward.

Locomotion

- The motion planning for the climbing robot aims to reduce the contact forces that could cause the grippers to detach from the surface, using reaction-aware motion planning.
- The swinging trajectory of the legs is constrained to a smooth polynomial curve and optimized to minimize the change in the generated momentum, reducing the induced motion reactions.

Locomotion

- Additionally, we compute the base motion that distributes the momentum generated by the swing motion to the robot’s whole body, minimizing the reactions during the swinging phase.
- With the definition of desired poses for the robot base and legs, we use a PD controller for the legs’ motors after computing the desired joint angles from inverse kinematics.

4. Results

Results

- A pose control experiment using the floating platform was performed to emulate landing, from an initial pose [0 m, 0 m, 0◦] to the set-point [0.3 m, 0.3 m, 20◦].

Results

- For translational axes, 1 N disturbance is applied. For orientation axis, 1 Nm disturbance is applied.

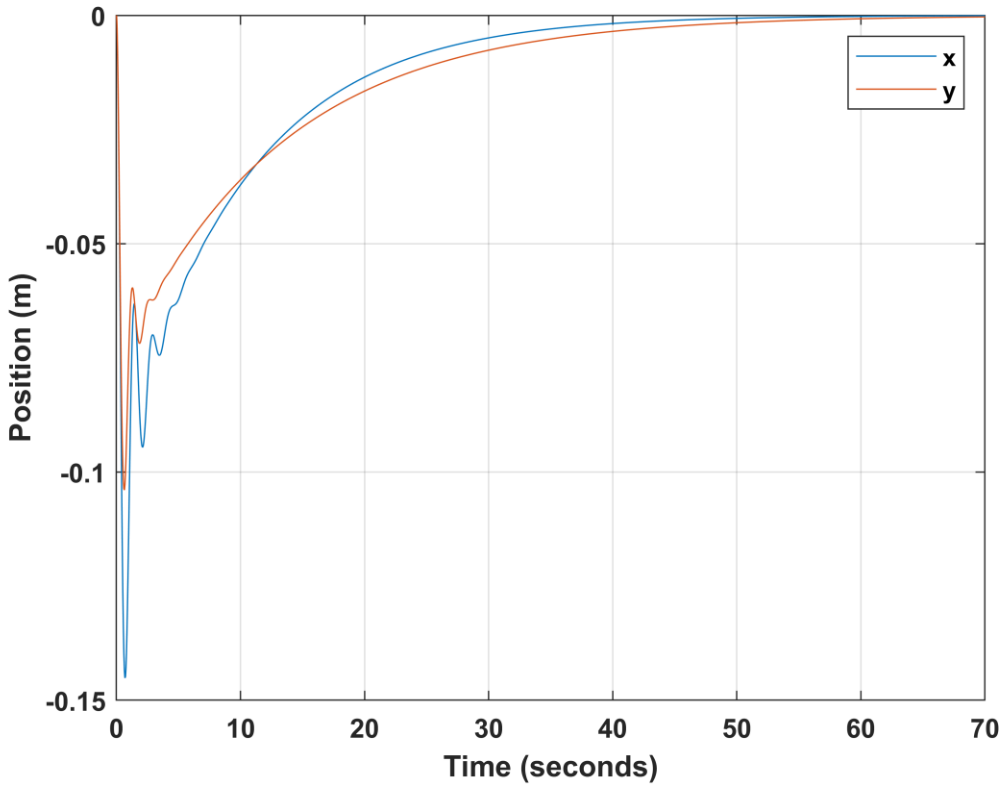


Fig. 4: Disturbance rejection simulation results - position.

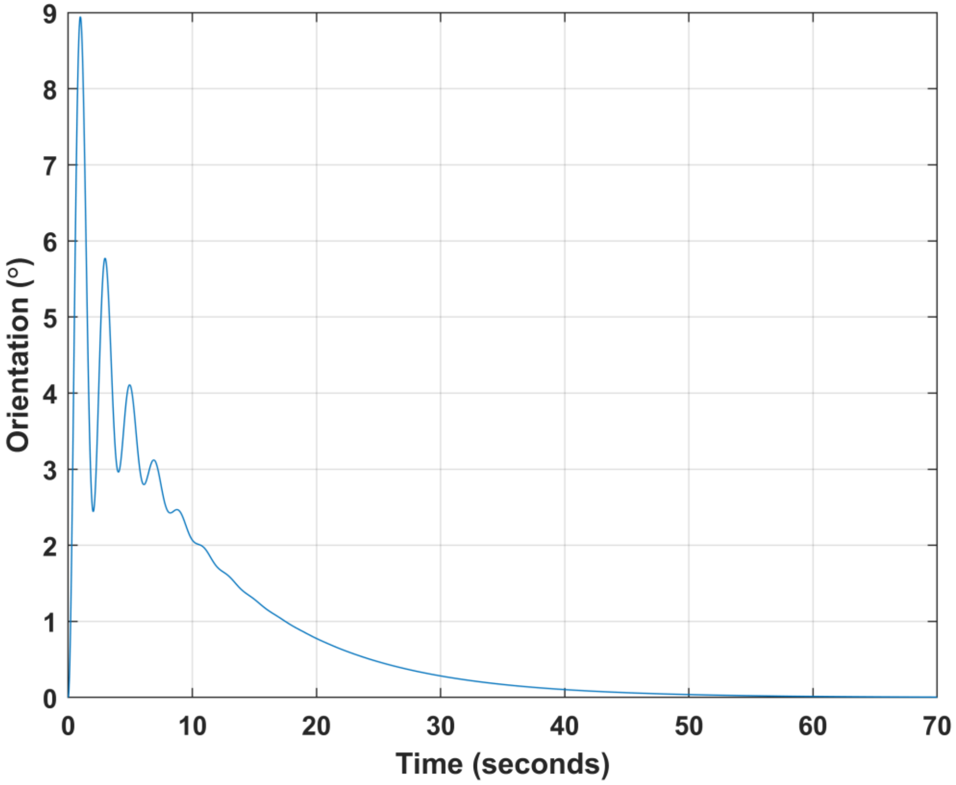


Fig. 5: Disturbance rejection simulation results - orientation.

Results

- The data shows that the controller satisfies asymptotic stability and convergence goals.

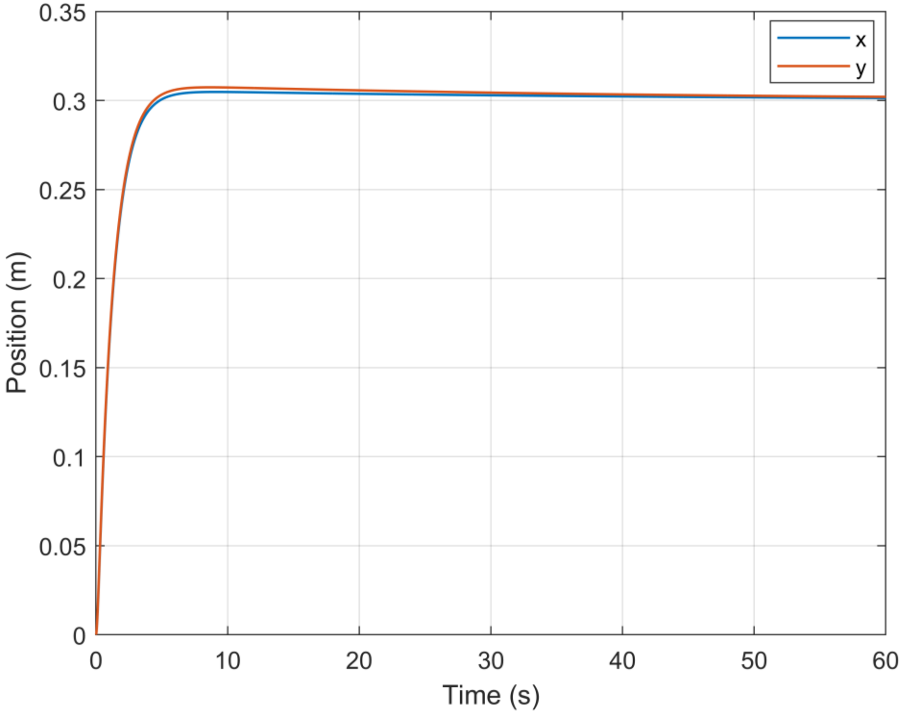


Fig. 6: Position control simulation results for landing.

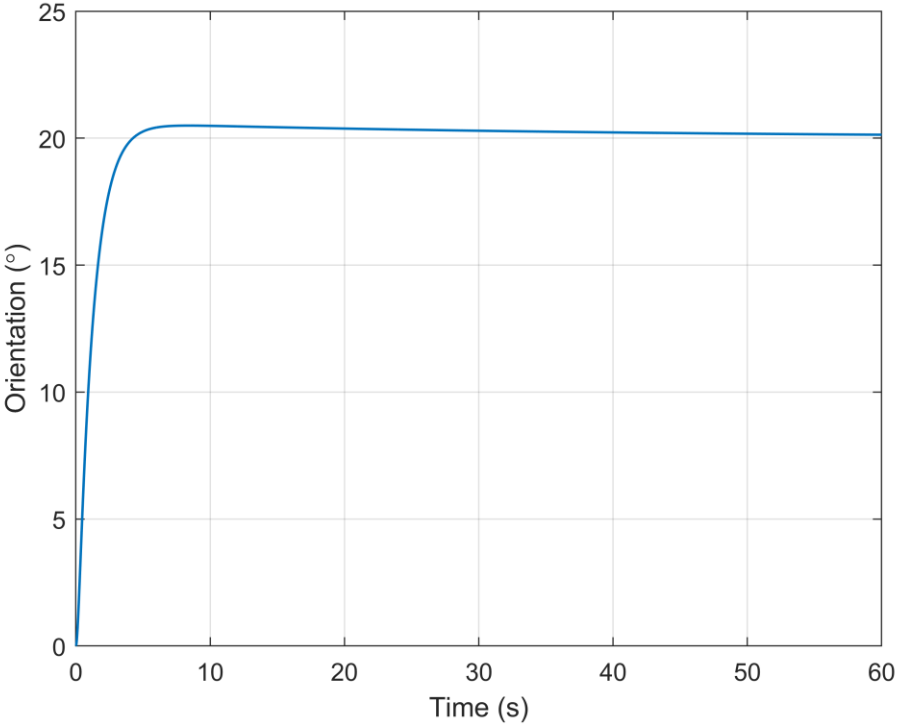


Fig. 7: Orientation control simulation results for landing.

Results

- The data shows that the controller satisfies asymptotic stability and convergence goals.

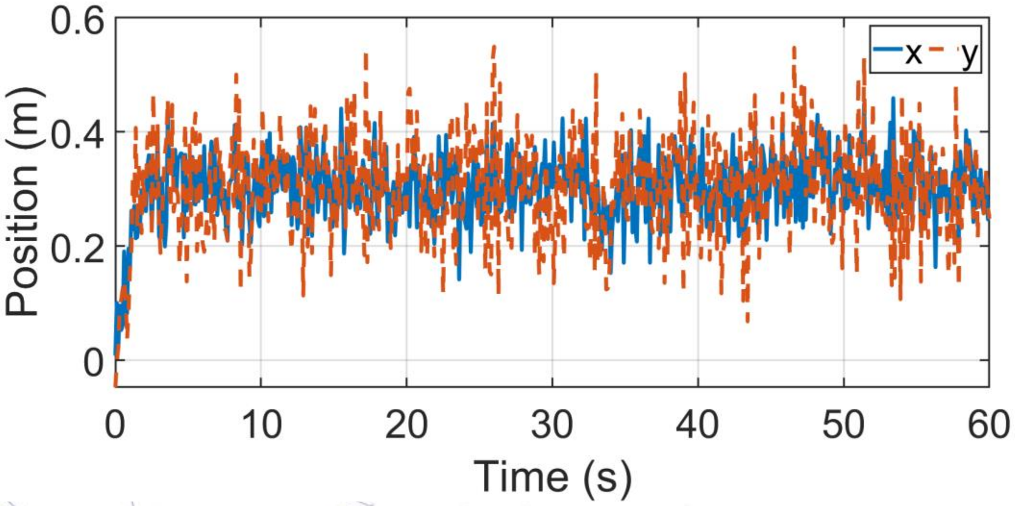


Fig. 6: Position control experiment results for landing.

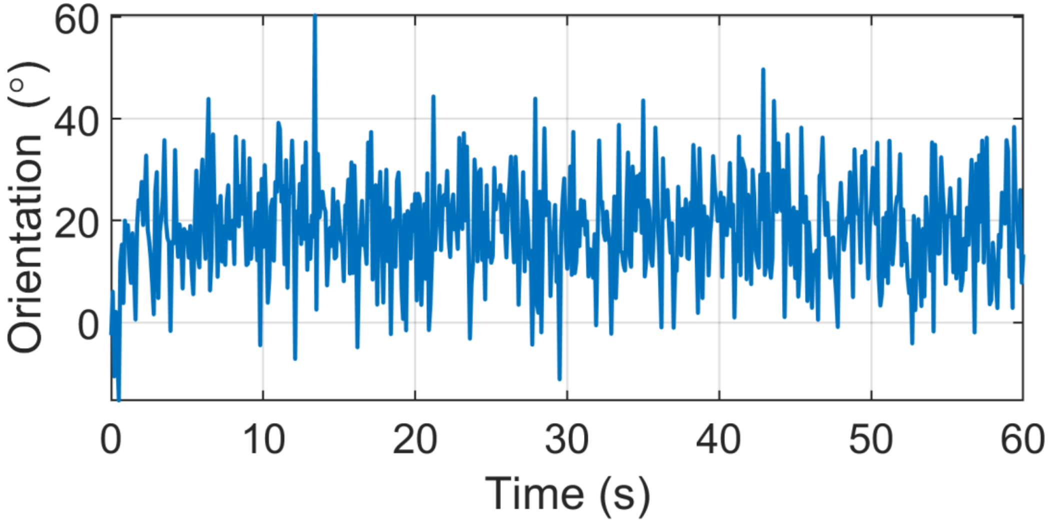
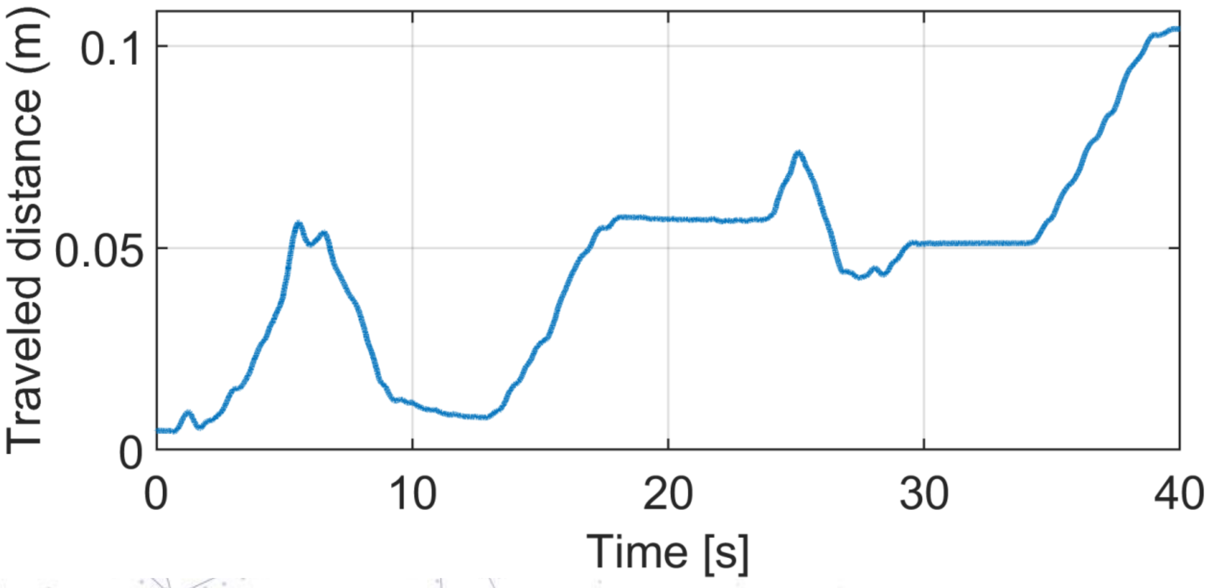


Fig. 7: Orientation control experiment results for landing.

Results

- For the locomotion experiment, we placed the robot using both grippers to grasp the targets on the wall to emulate the asteroid's surface. We computed the desired trajectories for the legs and base offline, executing a feedforward PD control for the joints to drive the robot toward its goal.



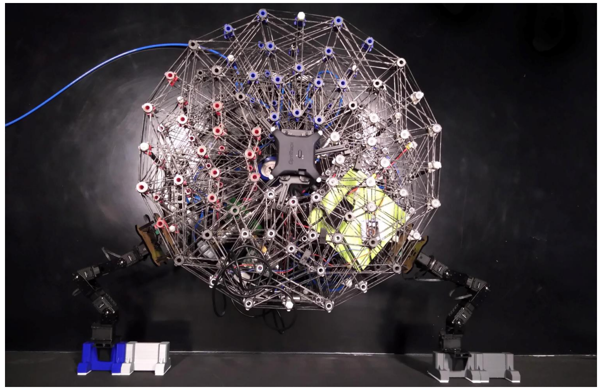


Fig. 8: Locomotion result, traveled distance.

5. Conclusion

Conclusions - Landing

- The controllers of both landing (floating platform) and locomotion (robotic arm) satisfy asymptotic stability and convergence goals.

Conclusions - Locomotion

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- Using the MCS available in the facility, we measured the robot's position, resulting in a total travel distance of approximately 10 cm, the same as planned offline before the experiment.
- Although the robot's position tracking did not fully match the planned trajectory, no significant issues happened, such as gripper detachment or slippage, and the robot successfully reached its goal position.

Conclusions - General

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- Considering the scenario of a legged climbing robot exploring an asteroid, we propose a strategy using a pose control for landing and reaction-aware motion planning for locomotion.
- Both methods were verified experimentally using an emulated microgravity facility, achieving the desired results for landing and locomotion.
- Using the proposed methods, the accuracy of the experimental results makes the floating platform a successful landing and locomotion emulator that can be used in orbital laboratories.

Thanks for listening, questions ?

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