Advances in Control Techniques for Floating Platform Stabilization in the Zero-G Lab

University of Luxembourg

Interdisciplinary Centre for
Security, Reliability and Trust

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Agenda

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1. **Introduction**
2. **Control Approach**
3. **Case Study / MPC – PD Comparison**
4. **Conclusion**

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1. Introduction

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Introduction

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- The pursuit of space exploration continues to push the boundaries of human understanding, presenting a plethora of challenges that demand innovative solutions.
- A pivotal aspect of this endeavor is the emulation of zero gravity conditions and the replication of intricate orbital scenarios *within controlled laboratory environments*.
- Such laboratories serve as crucibles for advancing our comprehension of orbital dynamics, spacecraft interactions, and autonomous systems.
- In SnT-University of Luxembourg, we have the Zero-G Lab, an orbital robotics facility we where realize orbital robotics scenario emulations.
- This innovative facility leverages a combination of robotic arms mounted on robotic rails, a super-flat epoxy-floor, and floating platforms to faithfully replicate microgravity conditions and support a diverse range of space-oriented experiments and research endeavors.

Introduction

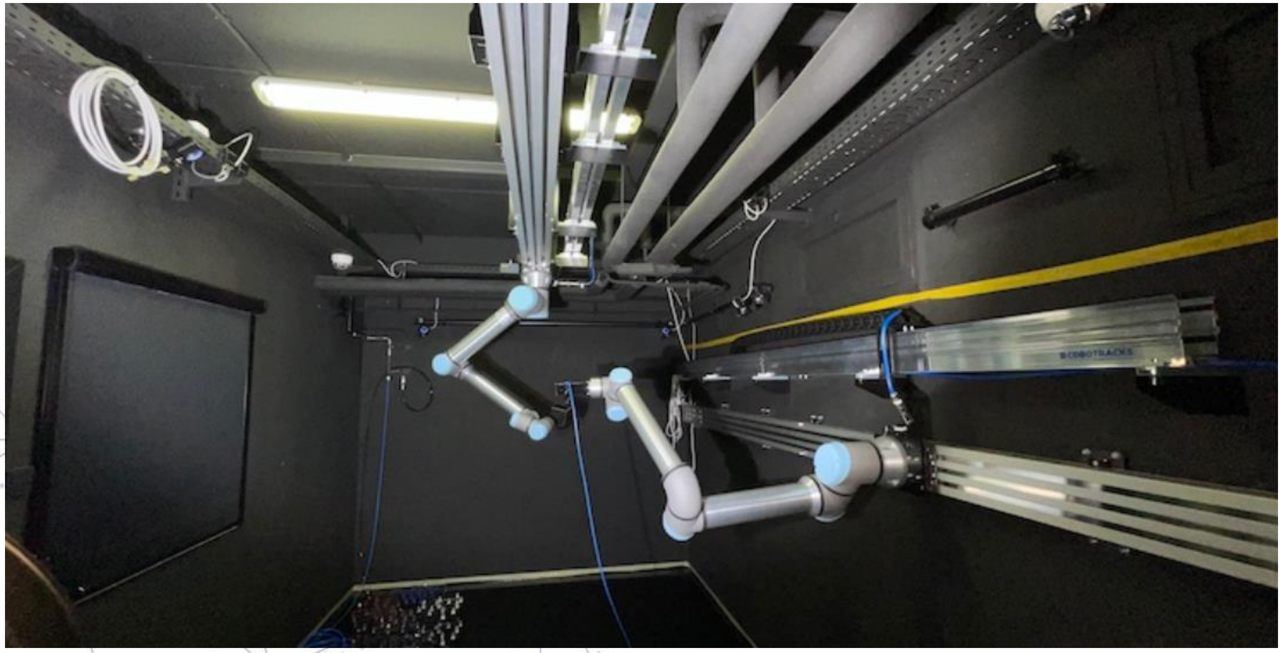

Fig. 1: The Zero-G Lab

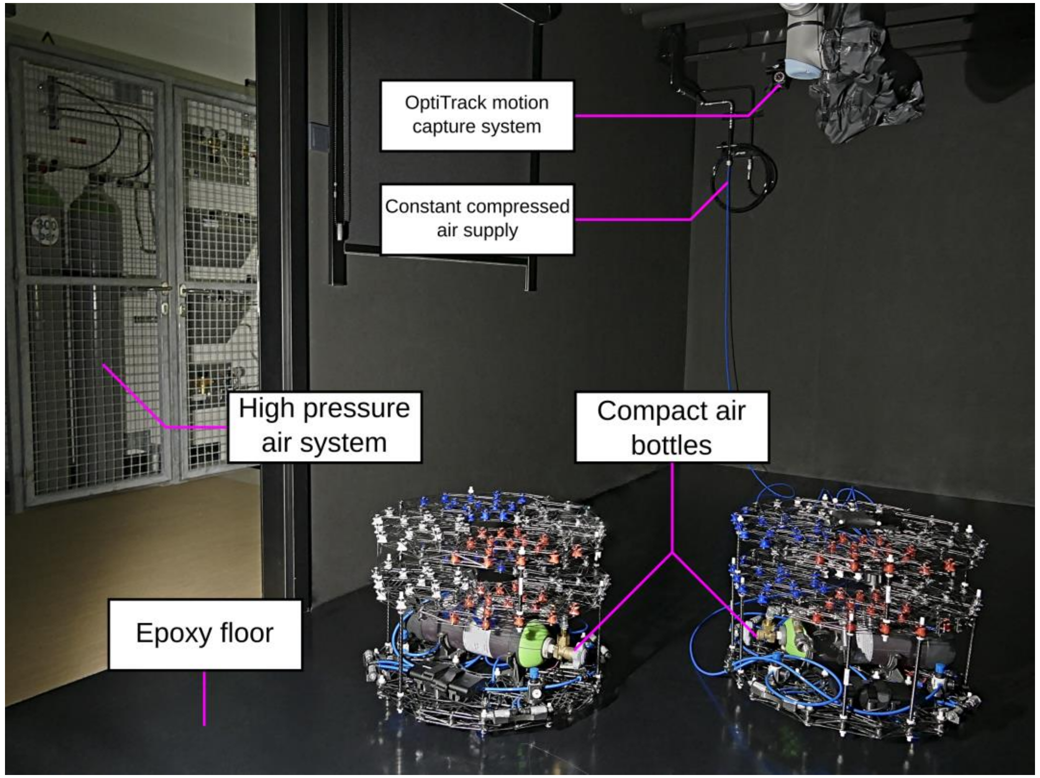

Fig. 2: Floating platforms inside the Zero-G Lab

Introduction

- The study presents a novel control approach for managing floating platforms in the unique environment of a zero-gravity laboratory (Zero-G Lab) of University of Luxembourg.
- These platforms are pivotal for diverse experiments and technologies in space. Our solution combines Model Predictive Control (MPC) and Proportional-Derivative (PD) control techniques to ensure precise positioning and stability.

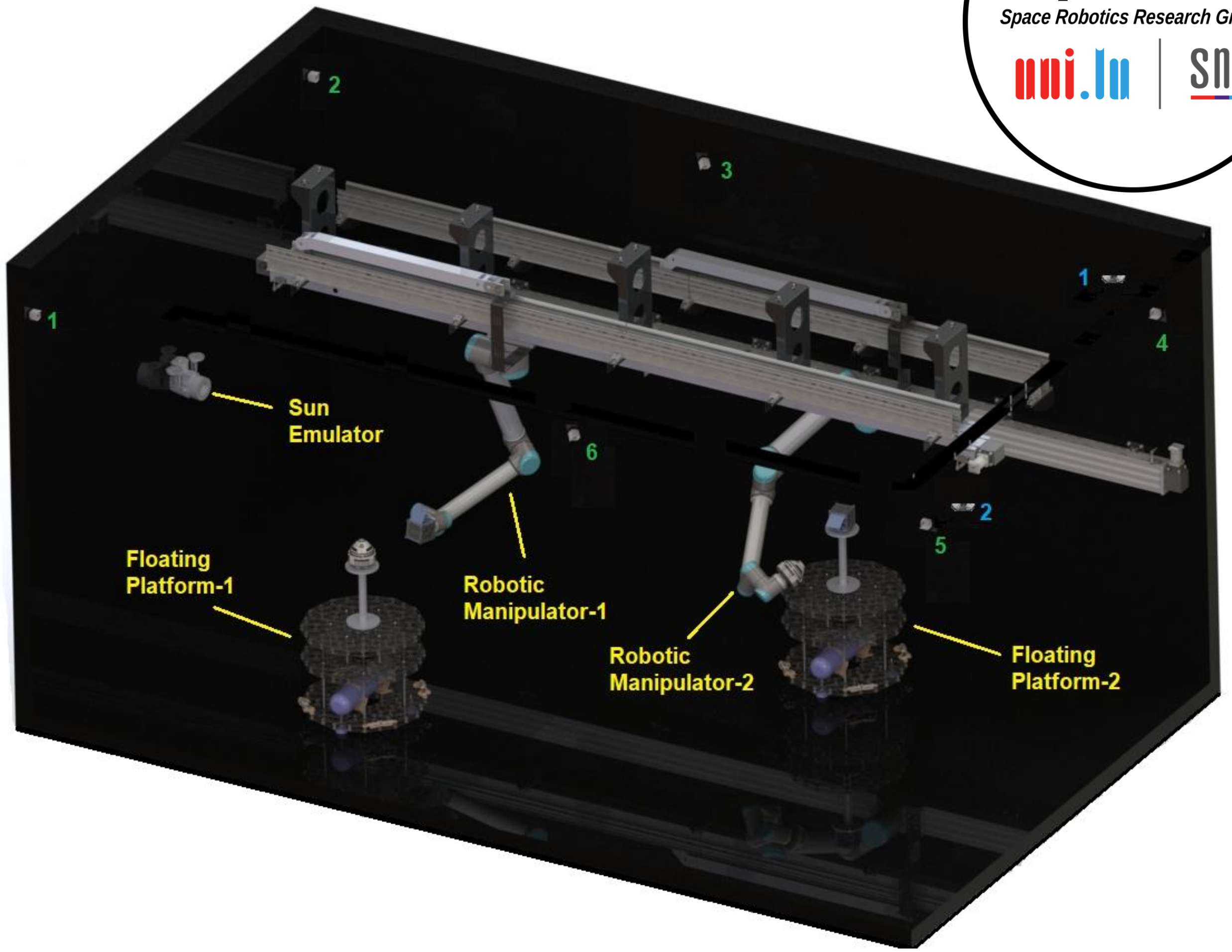

Fig. 3: Render of the Zero-G Lab

Introduction

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- The MPC algorithm generates optimal trajectories based on predictive platform models, adjusting paths for minimal effort.
- Augmented by a PD controller using feedback from the Optitrack motion system, real-time adjustments maintain stability by considering platform state, position, and orientation data.
- Extensive simulations and experiments within the Zero-G Lab demonstrate the effectiveness of our approach. The MPC-PD strategy accurately controls platforms, making them resilient against external disturbances and human interactions.
- This strategy holds promise for space exploration, microgravity experiments, and beyond, offering adaptable control in zero-gravity conditions.

Introduction

- SpaceR's floating platform is made of light-weight string-like Carbon fiber material which increases the experiment time.

- The floating platform is integrated into the ROS network, and a ROS-MATLAB bridge facilitates platform programming using MATLAB, enabling experimentation and assessment of its capabilities, including maintaining position under disturbances and trajectory tracking.

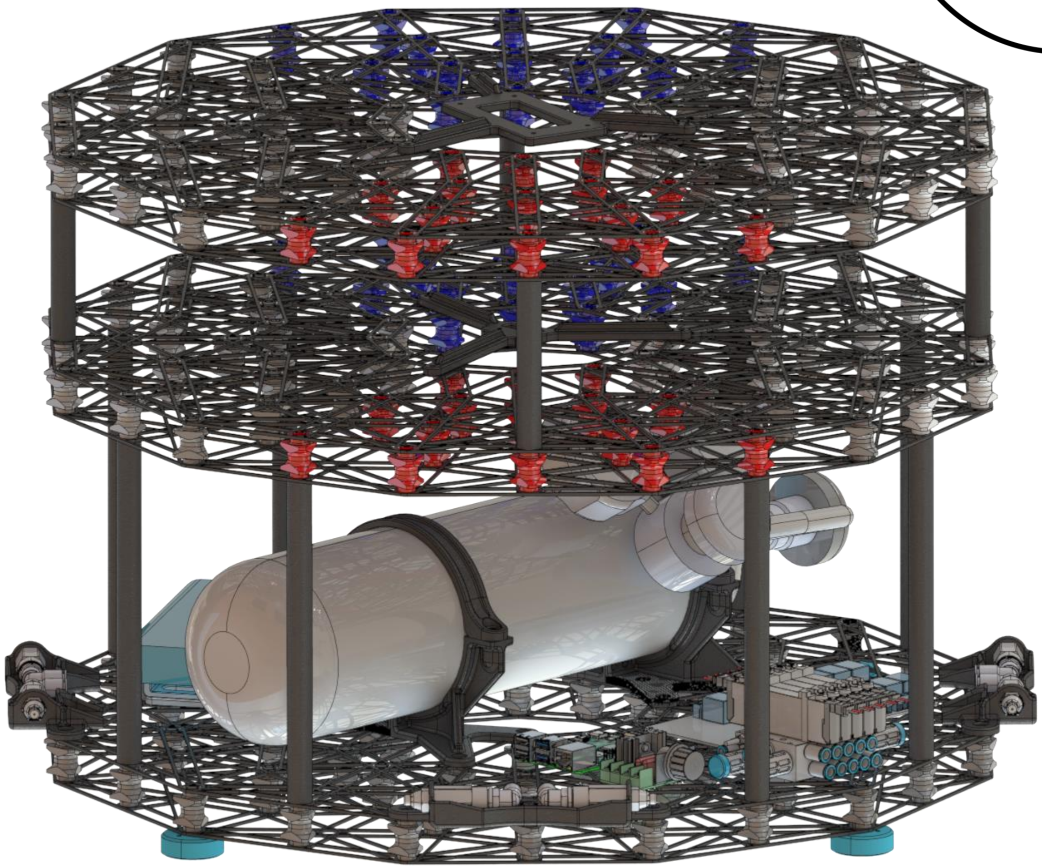

Fig. 4: SpaceR's floating platform

Introduction

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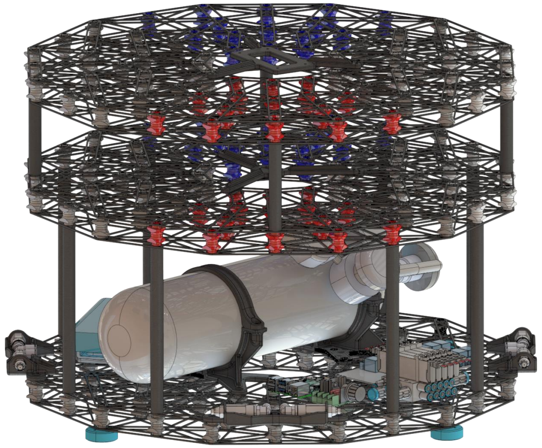
The national patent application in Luxembourg named "Pneumatic floating systems for performing zero-gravity experiments" has been filed and it is still under evaluation process, the patent application file number is LU503146.



2. Control Approach

Control Approach

- The control scheme encompasses two distinct methodologies: PD control and integrated MPC-PD control

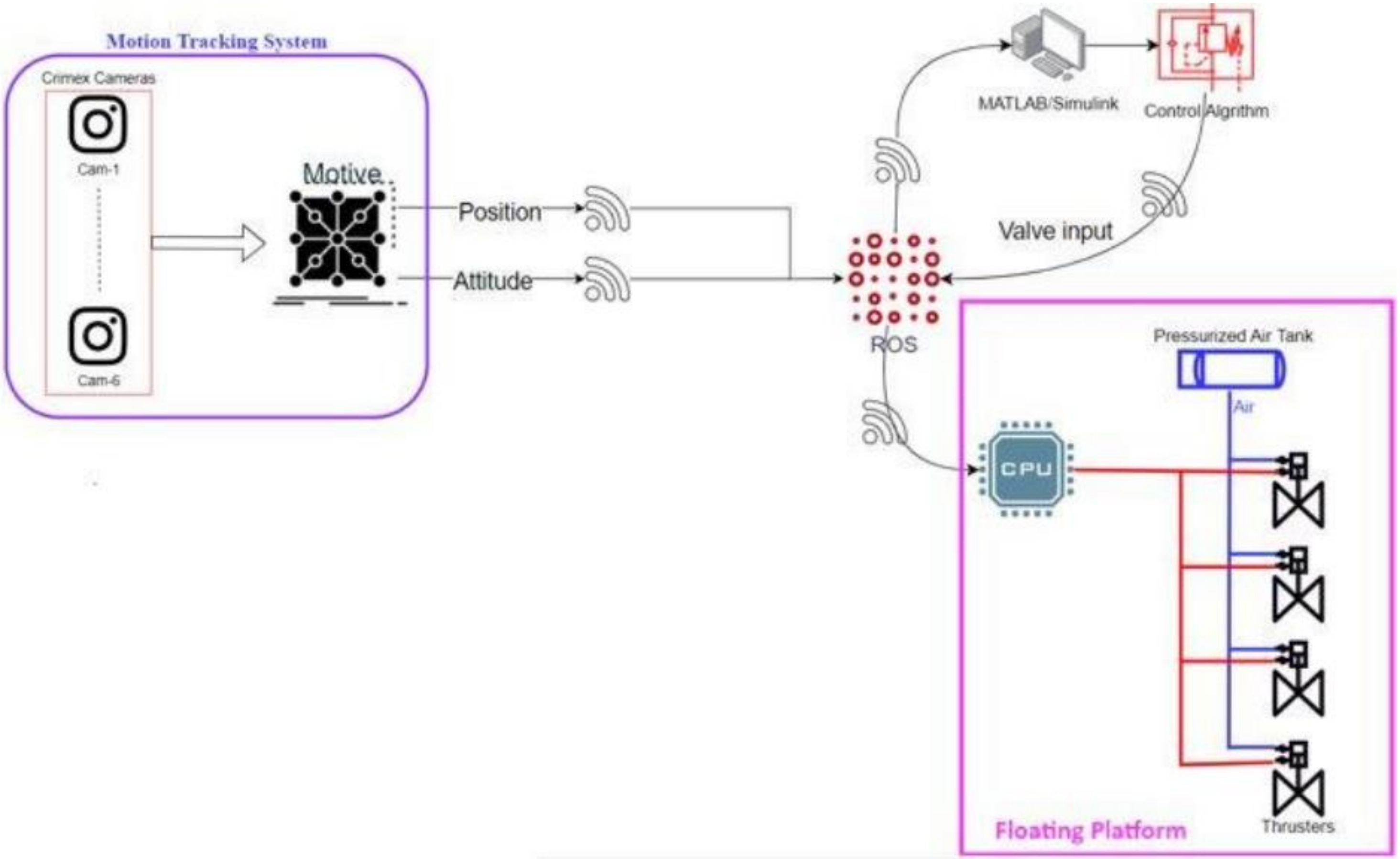


Fig. 5: Dataflow

Control Approach

- To translate the continuous analog control commands into discrete digital signals suitable for the control of the floating platform, we incorporate a saturation module. This module efficiently limits the control commands’ amplitude within a predefined range.
- This approach enhances control accuracy and stability, especially in scenarios where the floating platform operates with discrete on/off control signals.

Integrated MPC-PD Control Approach

- MPC with PD control to enhance the precision and responsiveness of the floating platform’s control. Within this framework, MPC is responsible for generating a reference trajectory tailored for efficient docking.
- The PD controller is then employed to track this reference trajectory. This integrated approach enhances the control system’s performance during docking operations.

Integrated MPC-PD Control Approach

- MPC entails the minimization of a cost function that quantifies the disparities between the state of the floating platform, and the desired final states, represented, in conjunction with the control inputs. This optimization process takes into account system dynamics and constraints, and it is solved iteratively by MPC to dynamically adjust control inputs in response to uncertainties and disturbances

$$\min_{\boldsymbol{u}} \int_{t=t_0}^{t_f} [\|\boldsymbol{x}(t) - \boldsymbol{x}_d\|_{\Omega}^2 + \|\boldsymbol{u}(t)\|_{\omega}^2] dt \qquad (1)$$

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3. Case Study

The case study / Disturbance rejection

- The case study consists of three-fold simulations; 1- Disturbance rejection, 2- Set-point tracking with PD controller, 3 Set-point tracking with PD controller in which set-points determined by MPC.

- The disturbance value applied to the floating platform is 1 N for each translational x and y axes, and 1 Nm for rotational z axis. The floating platform gets back to its initial position [0, 0, 0] after the disturbance vector is applied. Since there is no specific trajectory generation, MPC does not play a role in this particular scenario.

The case study / Disturbance rejection

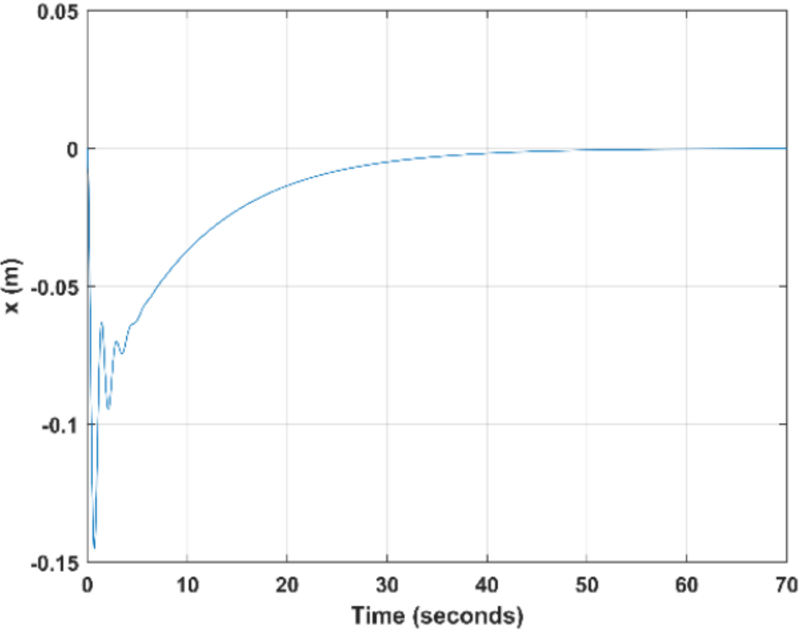

Fig. 6: Disturbance rejection – translational x axis

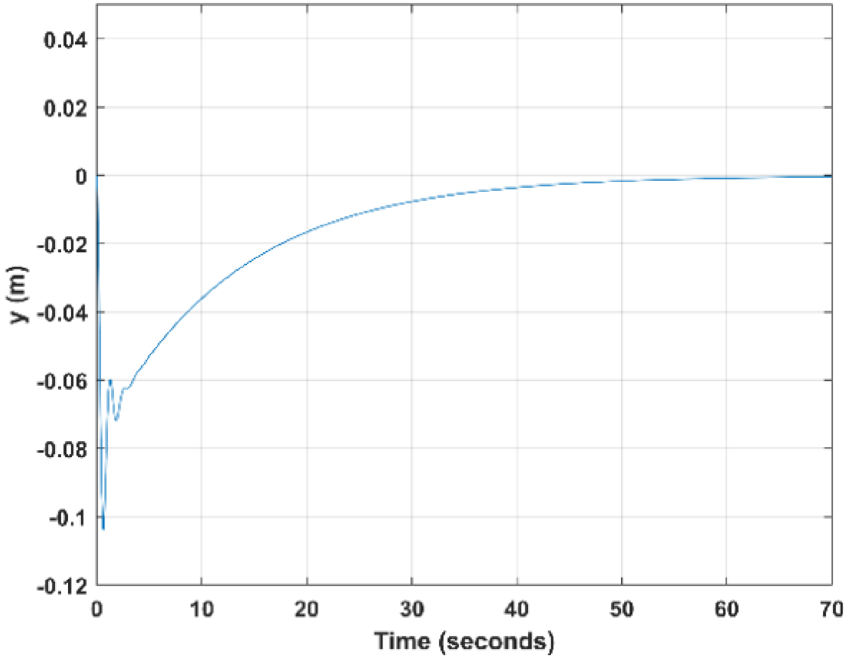

Fig. 7: Disturbance Rejection – translational y axis

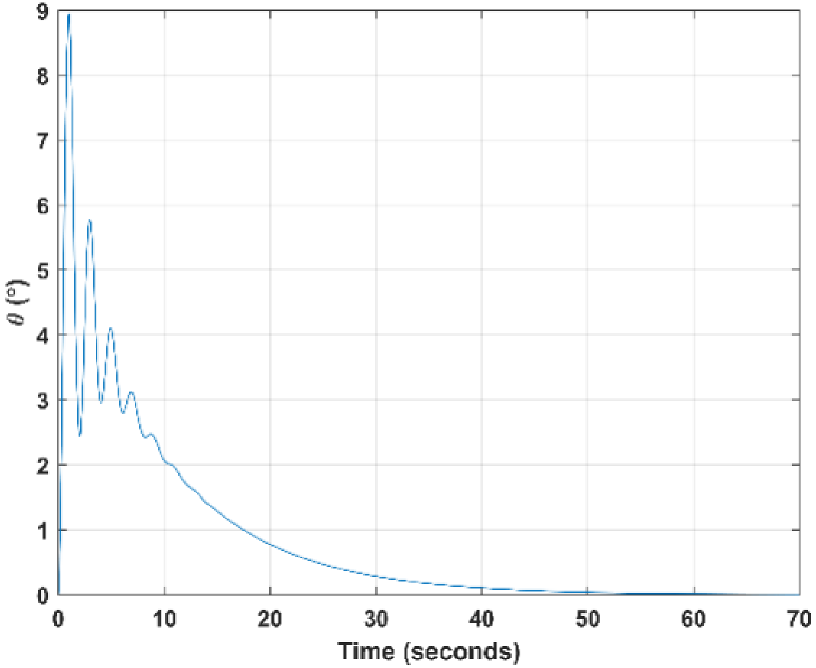

Fig. 8: Disturbance rejection - rotational z axis

The case study / Comparison between “set-point tracking with PD controller” and “set-point tracking with PD controller in which set-points determined by MPC”.

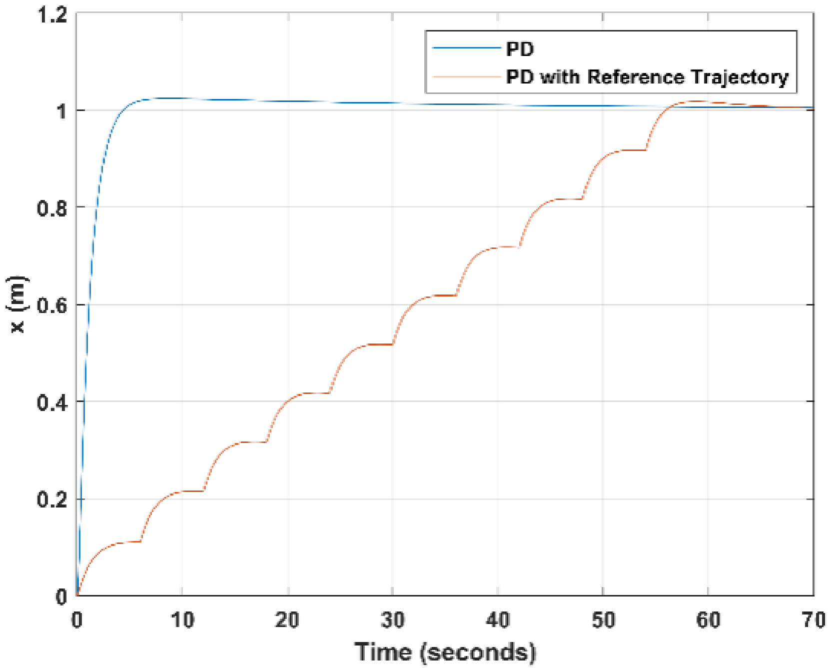

Fig. 9: Disturbance rejection – translational x axis

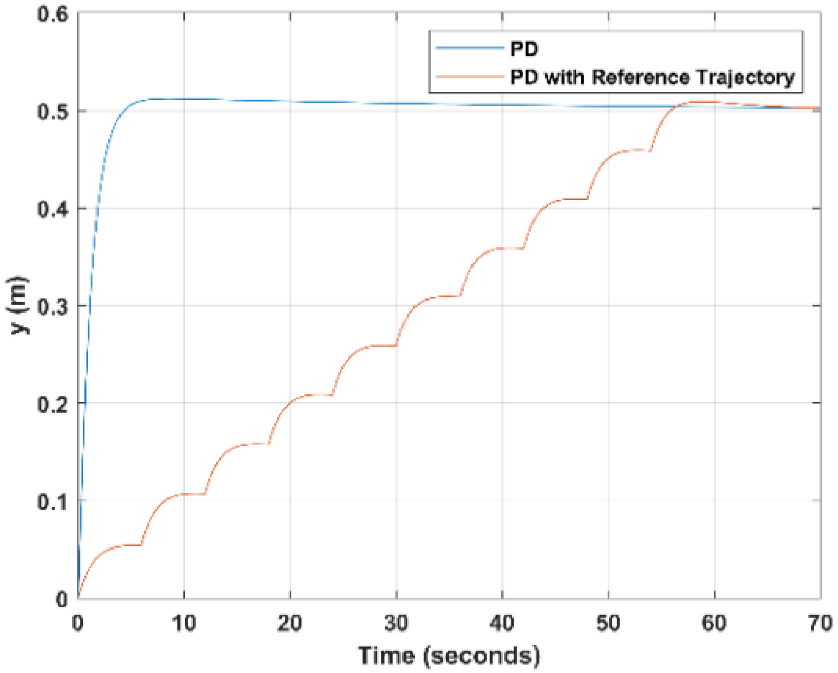

Fig. 10: Disturbance Rejection – translational y axis

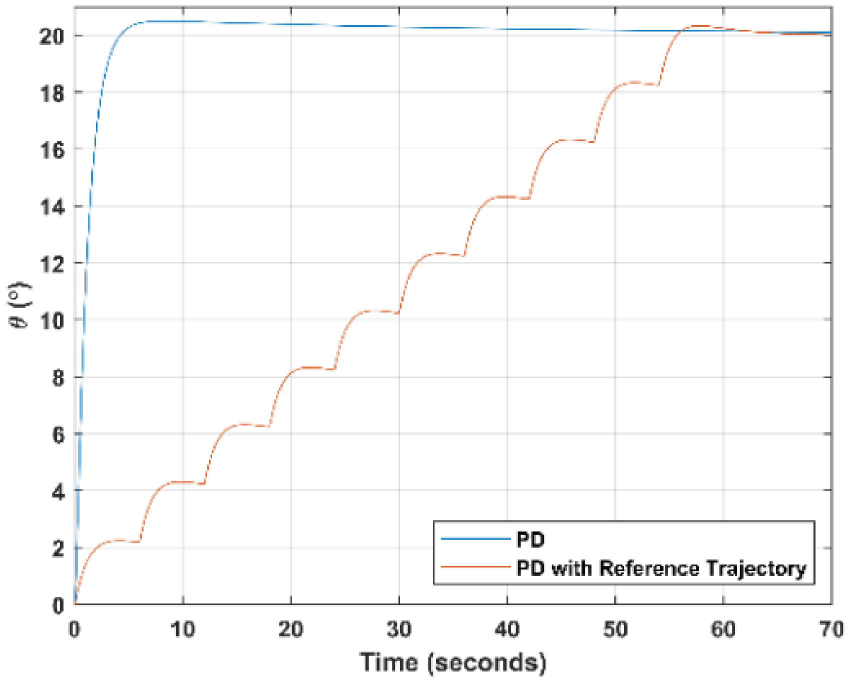

Fig. 11: Disturbance rejection - rotational z axis

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5. Conclusion

Conclusion

- Our simulations affirm the PD controller’s robustness in mitigating disturbances.
- When utilizing the trajectory generated by MPC, we observed reduced overshoot compared to the PD controller, which gives certain advantages for particular cases, such as contact dynamics, close proximity, and docking.

Conclusion

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- These findings hold significant implications for control theory and applications in space exploration, pointing to the potential benefits of combining PD and MPC for enhanced precision and reliability in microgravity control.

Thanks for listening, questions ?

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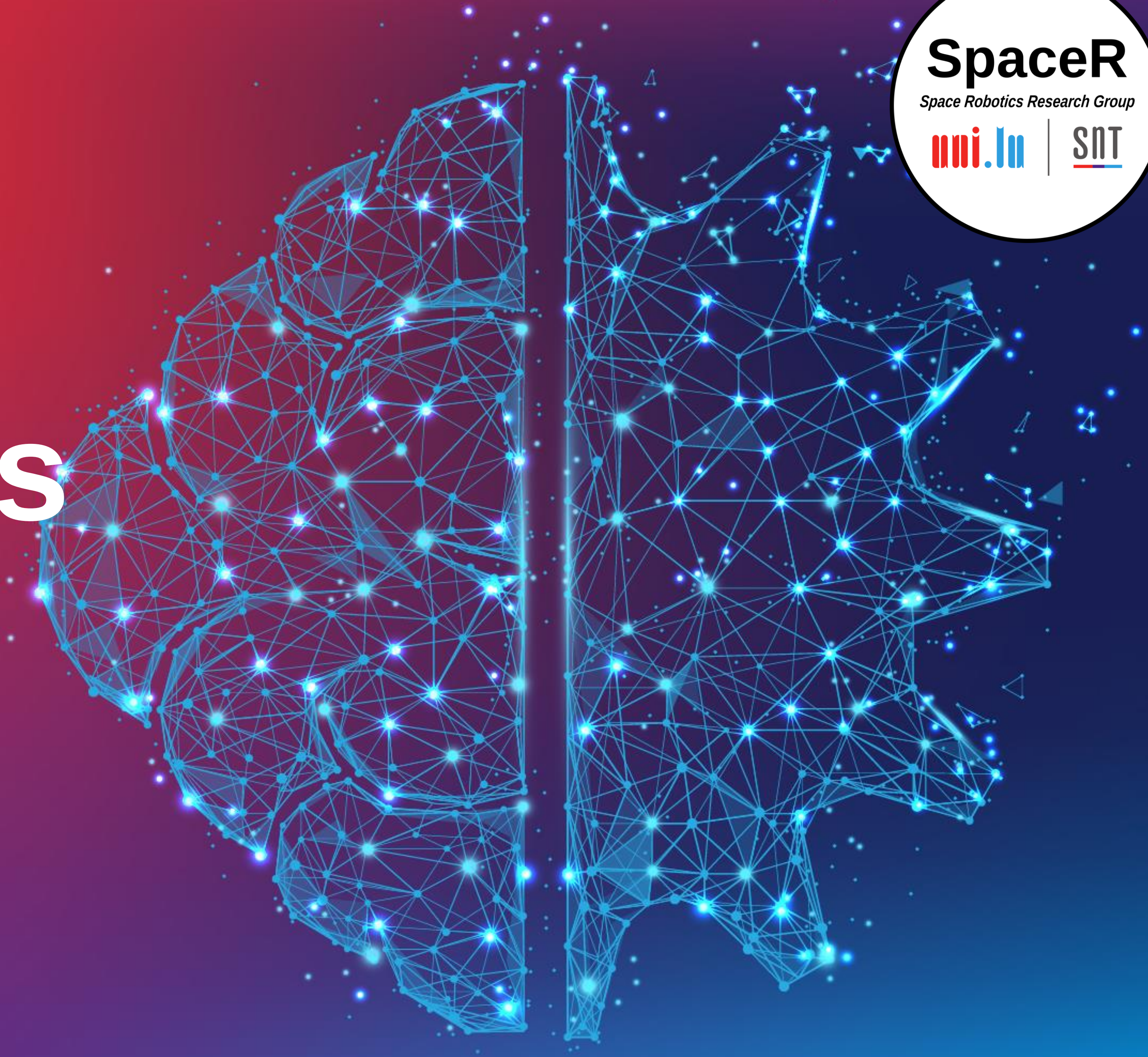

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