New Mexico Research Spotlight Forum

4/17/2019 Advancing Resilience for Space Systems

Predictive and Robust Guidance and Control for Space Systems

PRESENTED BY:

Hyeongjun Park, Ph.D.

Mechanical and Aerospace Engineering

New Mexico State University

575-646-2024, hjpark@nmsu.edu

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ABOUT MYSELF – HYEONGJUN PARK

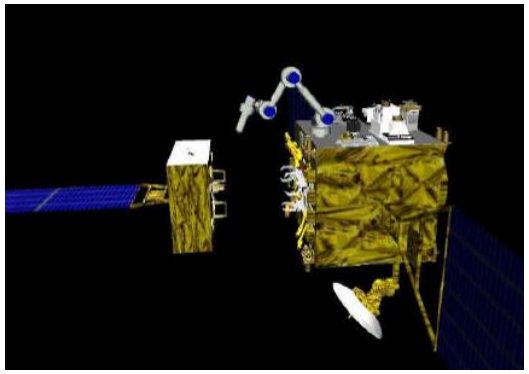
- **Brief biography**
  - Education
    - Ph.D., Aerospace Engineering, University of Michigan 2014
    - B.S./M.S., Aerospace Engineering, Seoul National University, South Korea, 2003/2008
  - Professional Experience
    - Assistant Professor, Mechanical and Aerospace Engineering, New Mexico State University, 2018-present
    - National Research Council Research Associate, Spacecraft Robotics Lab, Naval Postgraduate School, CA, 2015-2017
- **Research areas**
  - Onboard real-time spacecraft guidance and control
  - Precision spacecraft attitude control and failure analysis
  - Real-time model predictive control
  - Applications: spacecraft rendezvous and docking, precision satellite attitude control, hypersonic vehicles

Keywords:

Real-Time Optimal Guidance and Control; Robust Attitude Control; Failure Analysis

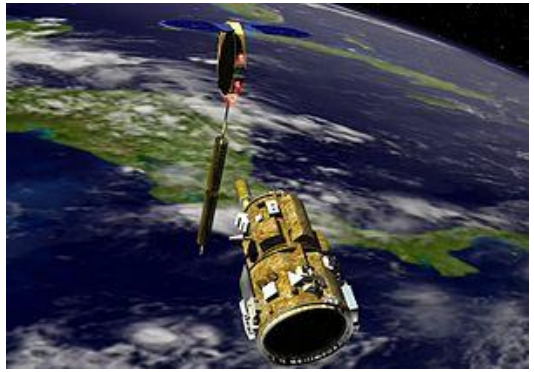
CURRENT WORK I – Spacecraft Onboard Guidance & Control

- **Rendezvous and Proximity Operations (RPO)**
  - Docking, berthing, servicing, inspection, active debris removal, etc.



ETS-VII (1998, JAXA)

Image Courtesy of JAXA



DART (2005, NASA)

Image Courtesy of NASA

ATV (2008, ESA)

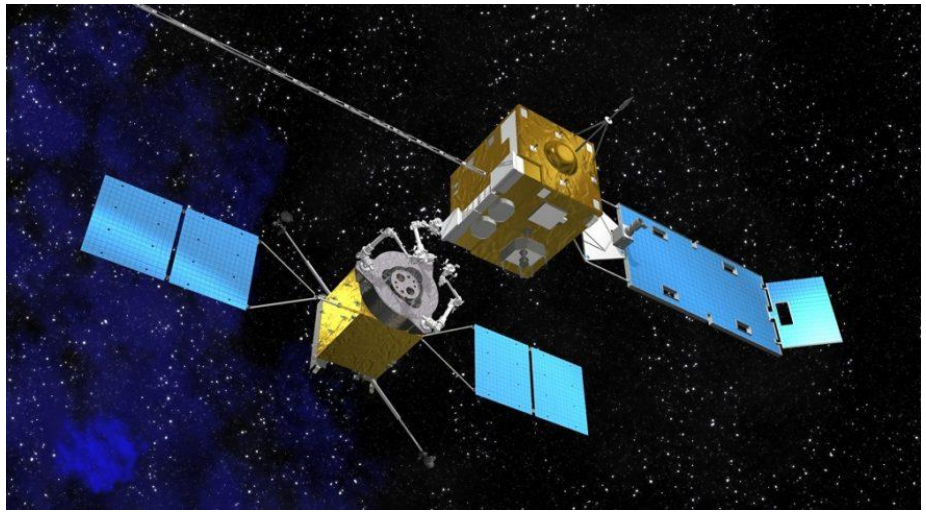
Image Courtesy of ESA

Dragon (2019, SpaceX)

Image Courtesy of NASA

CURRENT WORK I – Spacecraft Onboard Guidance & Control

- **Docking with a rotating/tumbling target platform**
  - Recovery of out-of-control satellite
  - Advanced future missions for Mars and deep space explorations



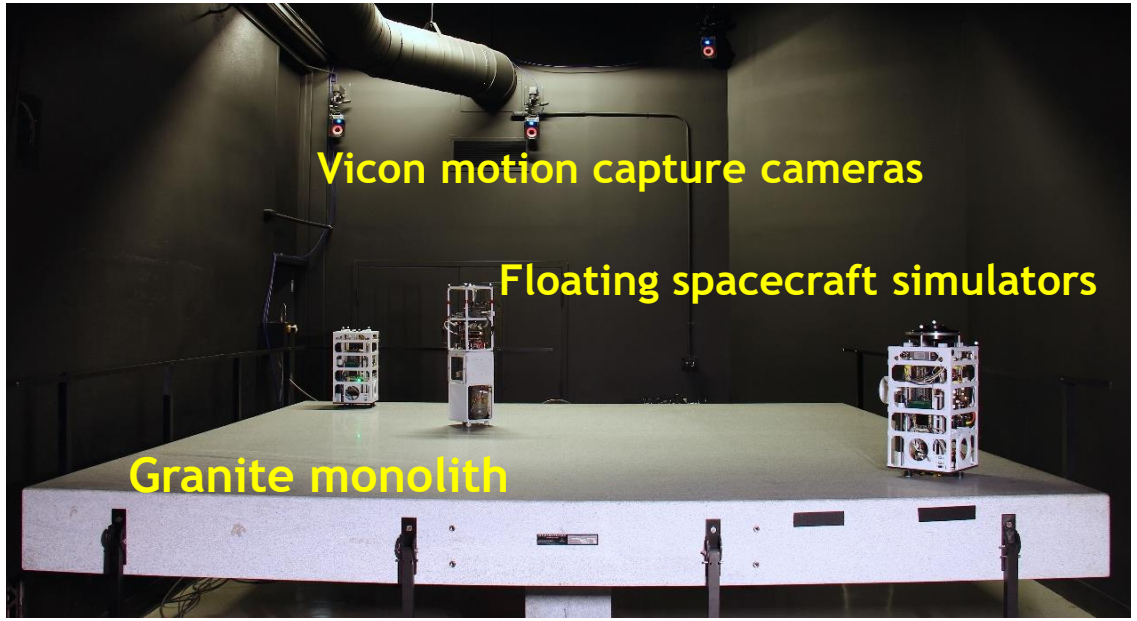
→ **Autonomous real-time collision-free mission strategies and algorithms are necessary for autonomous inspection, recovery, and removal capabilities**

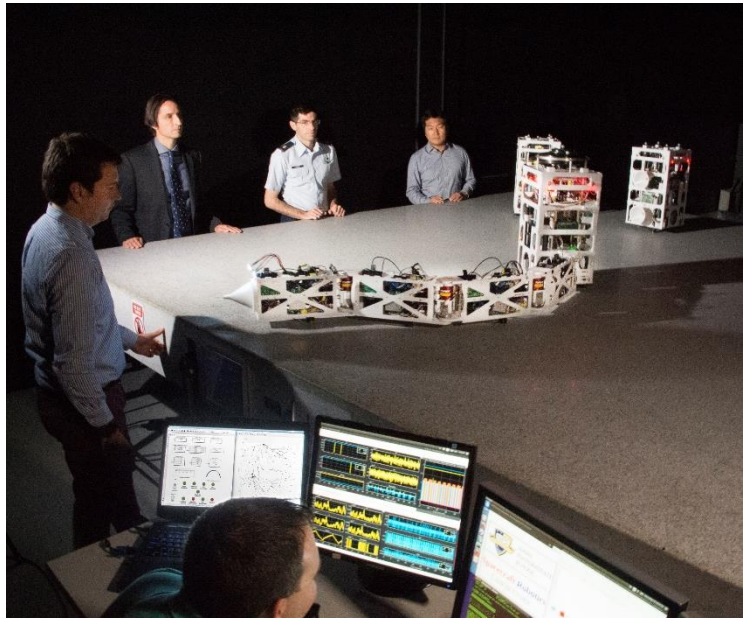
CURRENT WORK I – Spacecraft Onboard Guidance & Control

- **Experimental Testbed**

NPS-POSEIDYN testbed for quasi-frictionless environment

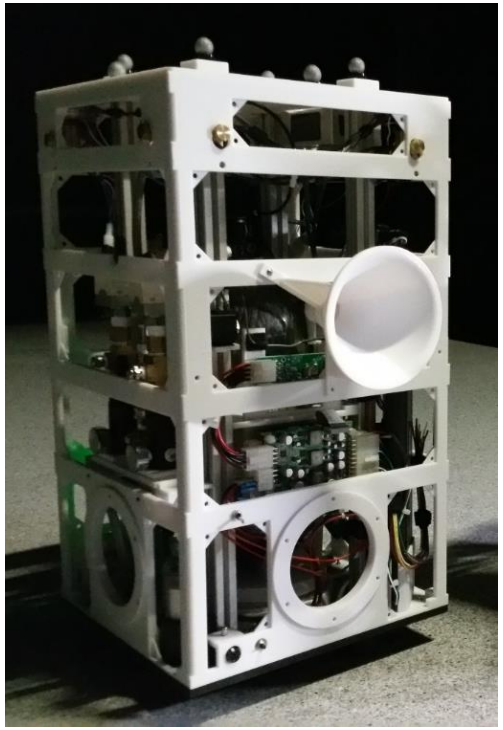
- Naval Postgraduate School – Proximity Operation of Spacecraft: Experimental hardware-In-the-loop DYNamic simulator test bed





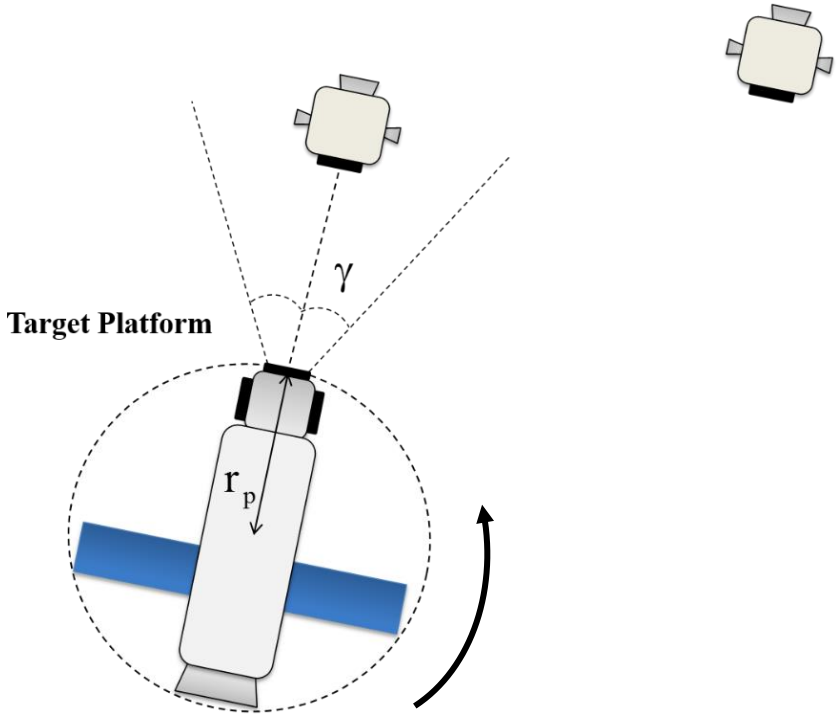
CURRENT WORK II – Spacecraft Onboard Guidance & Control

- **Floating Spacecraft Simulators**
  - ~10 kg vehicle
  - 3000 psi 1.8L compressed air tank
  - 3x air bearings (at 60 psi)
  - 8x thrusters (~0.16 N each)
  - Onboard computer
    - PC104-Plus board with Intel Atom 1.6GHz 32-bit with 2GB DDR2 RAM and 8GB SSD
  - Software
    - Ubuntu 14.04 LTS 32 bit edition
    - RTAI kernel patch for real-time execution



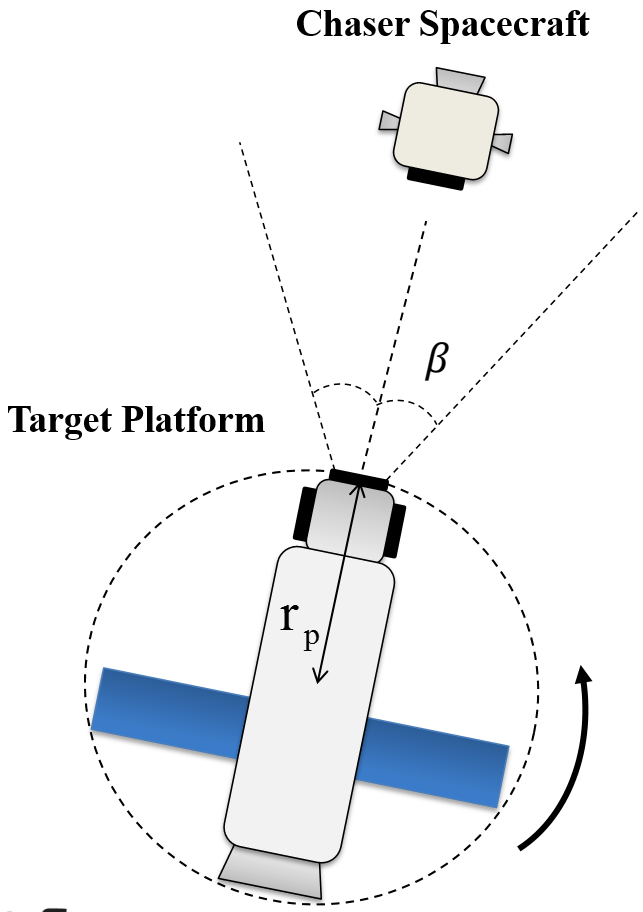
CURRENT WORK I – Spacecraft Onboard Guidance & Control

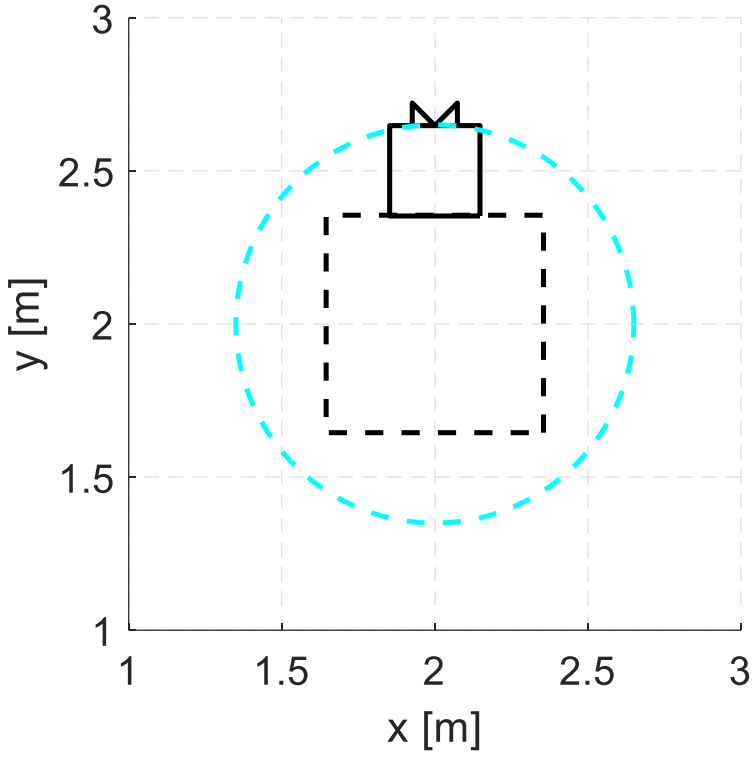
- **Rendezvous and docking strategy to design a computationally applicable**
- **Based on Nonlinear Model Predictive Control (NMPC) approach**
  - Phase 1: Free Flying
  - Phase 2: Final Docking Approach
  - Set a holding position as the desired positon of Chaser



CURRENT WORK I – Spacecraft Onboard Guidance & Control

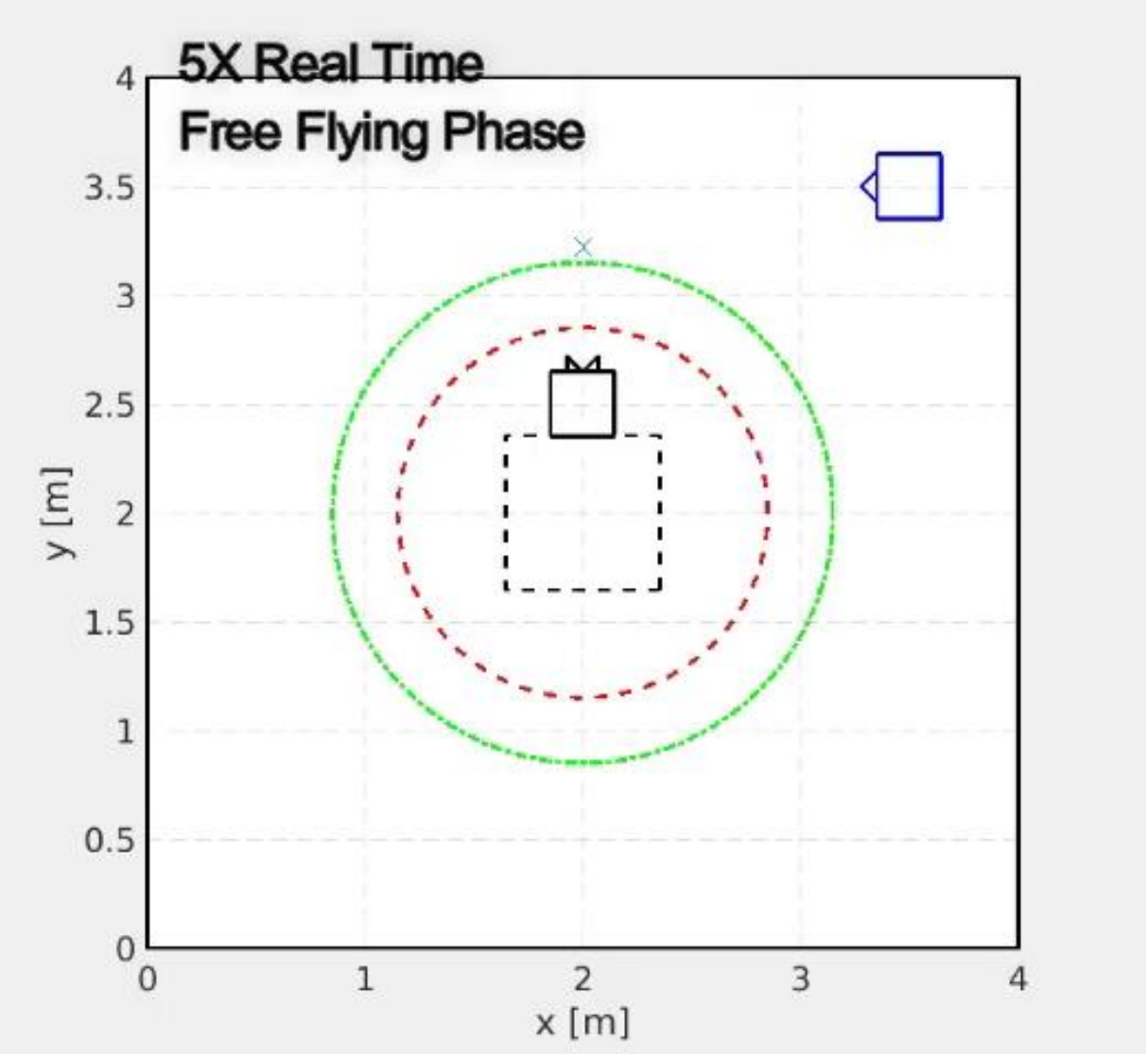
- **Mission design**
  - Emulating a docking port of a target platform using an FSS





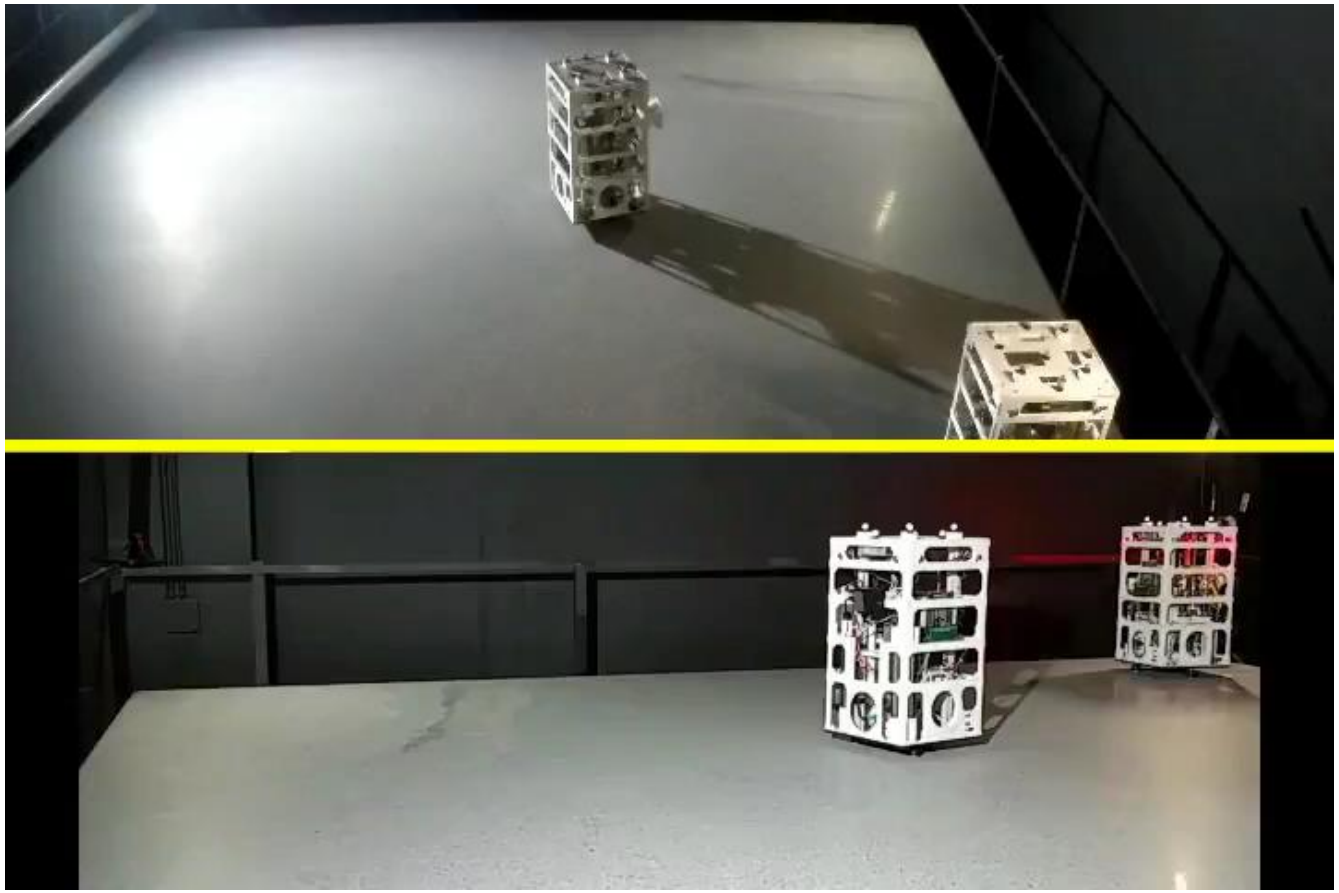
CURRENT WORK I – Spacecraft Onboard Guidance & Control

- **Simulation result**
  - IPOPT solver
  - Sample time: 2 s
  - Prediction horizon: 40
- Simulation: Agular rate: 1 deg/s



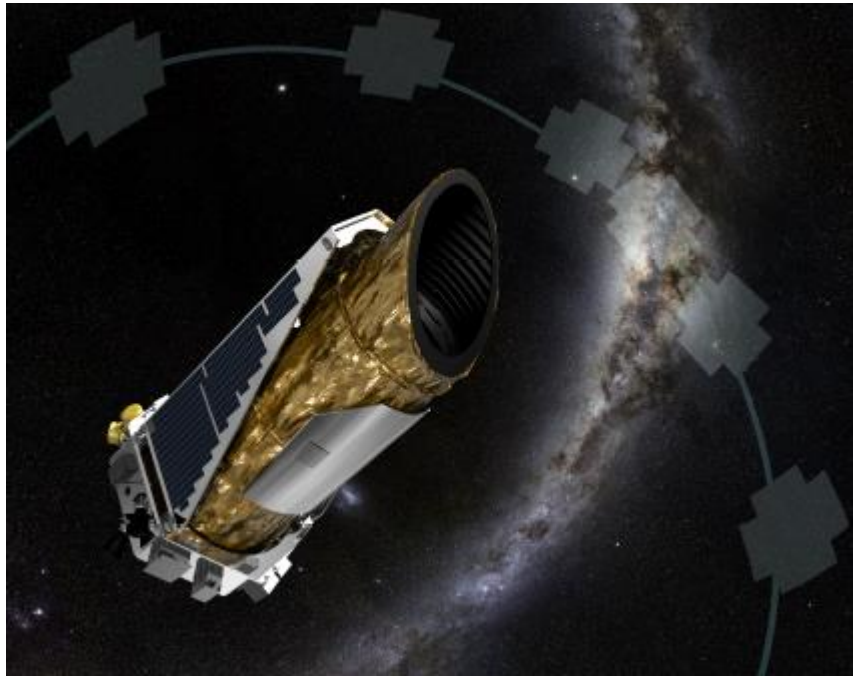
CURRENT WORK I – Spacecraft Onboard Guidance & Control

- **Experimental result: 0.5 deg/s, 4x real-time**
  - Avg & Max computation time: 0.04 s & 0.09 sec



CURRENT WORK II – Robust Attitude Control & Failure Analysis

- **Motivation**
  - Robust spacecraft attitude control: Design an H_∞ controller with Linear Matrix Inequalities (LMI) formulation
  - Fault detection method considering reaction wheel failure
  - Real mission scenarios



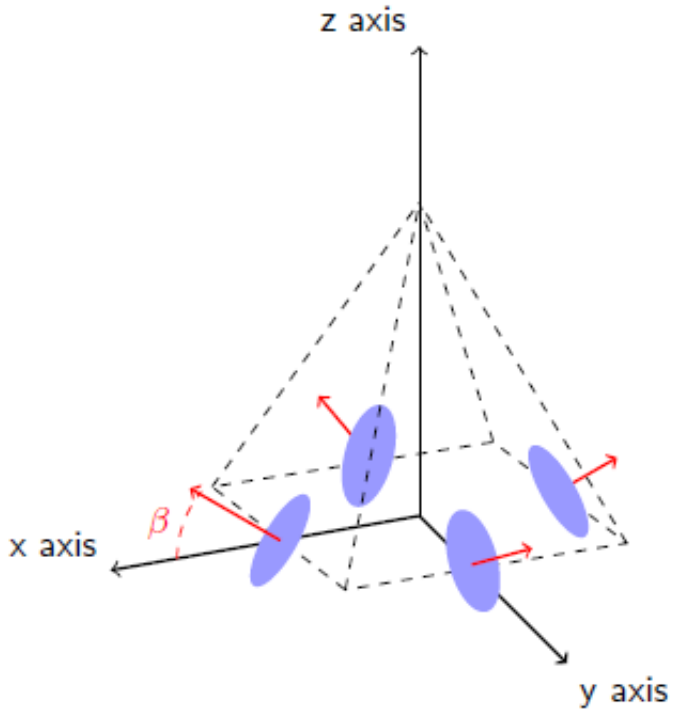
Artistic Concept of Mission Kepler, NASA

Image Courtesy of ESA

CURRENT WORK II – Robust Attitude Control & Failure Analysis

- **Mission scenario**
  - Small satellite of 200 kg, 0.8 m × 0.8 m × 1.2 m
  - Pyramid reaction wheel configuration of Honeywell HR16-50

Model	Mass [in Kg]	Max Angular momentum [in Nms]	Max torque [in Nm]	Inertia [in Kgm^2]
HR16-50	6	50	0.1	0.02



- Let consider this LTI system: $\begin{cases} \dot{x} = Ax + B_w w + B_u u \\ z = C_z x + D_{zw} w + D_{zu} u \end{cases}$
- State-feedback controller: $u = -Kx$
- Transfer function of the closed-loop system:

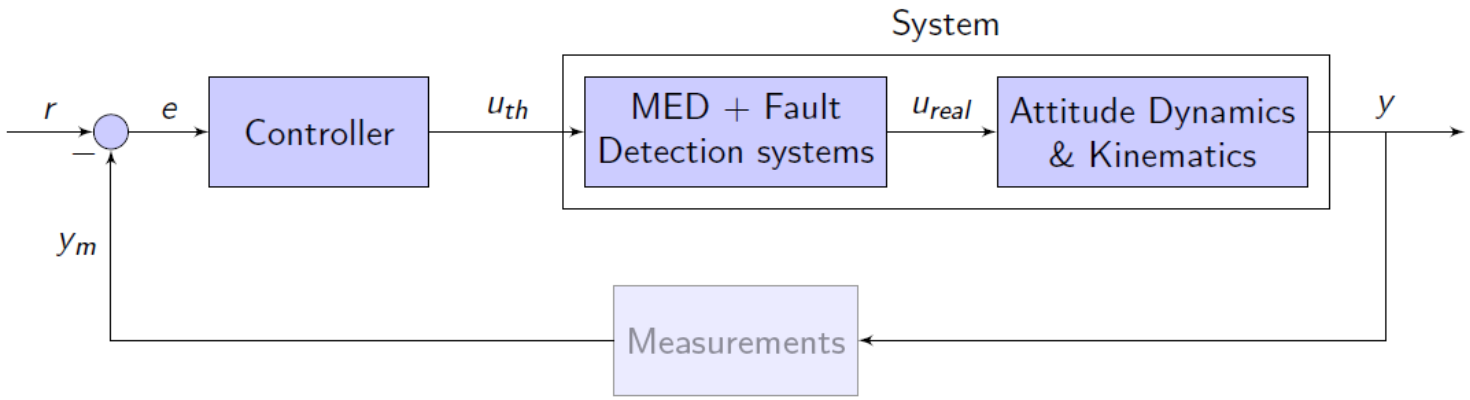
$$G(s) = D_{zw} + (C_z + D_{zu}K)(sI - A - B_u K)^{-1} B_w$$

Suboptimal H_∞ control

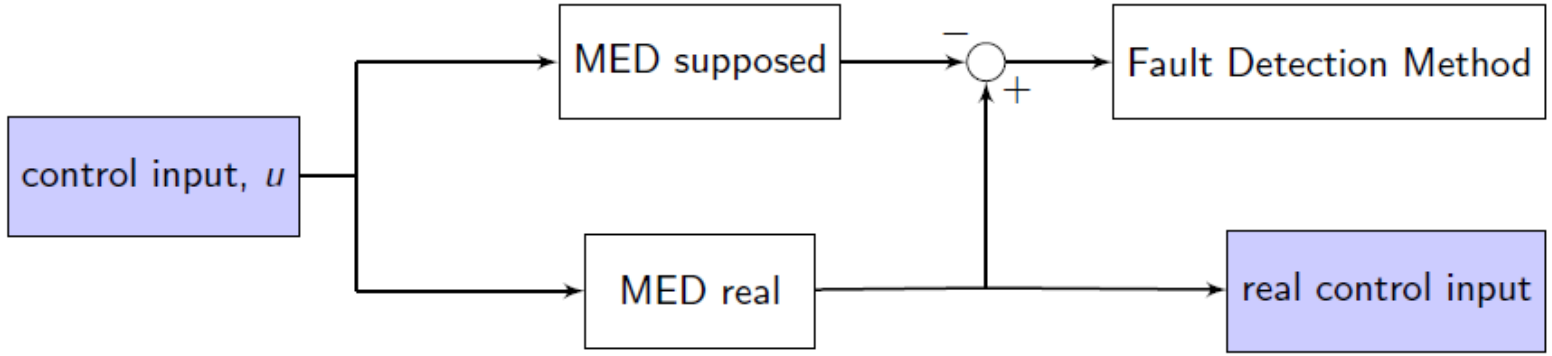
Given $\gamma > 0$, find all admissible controllers $K(s)$, if there are any, such that $\|G(s)\|_\infty = \max_\omega \bar{\sigma}(G(j\omega)) \leq \gamma$

CURRENT WORK II – Robust Attitude Control & Failure Analysis

- **System description**



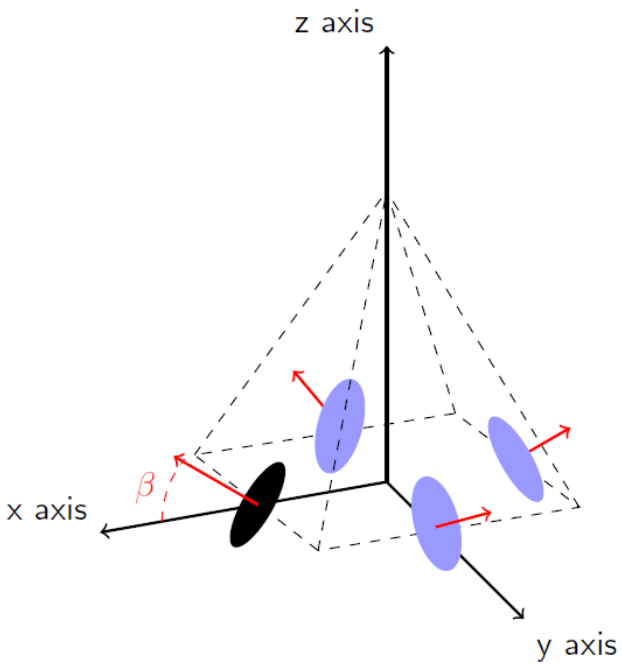
- **Fault detection method:** Parity equations method based on analytical redundancy

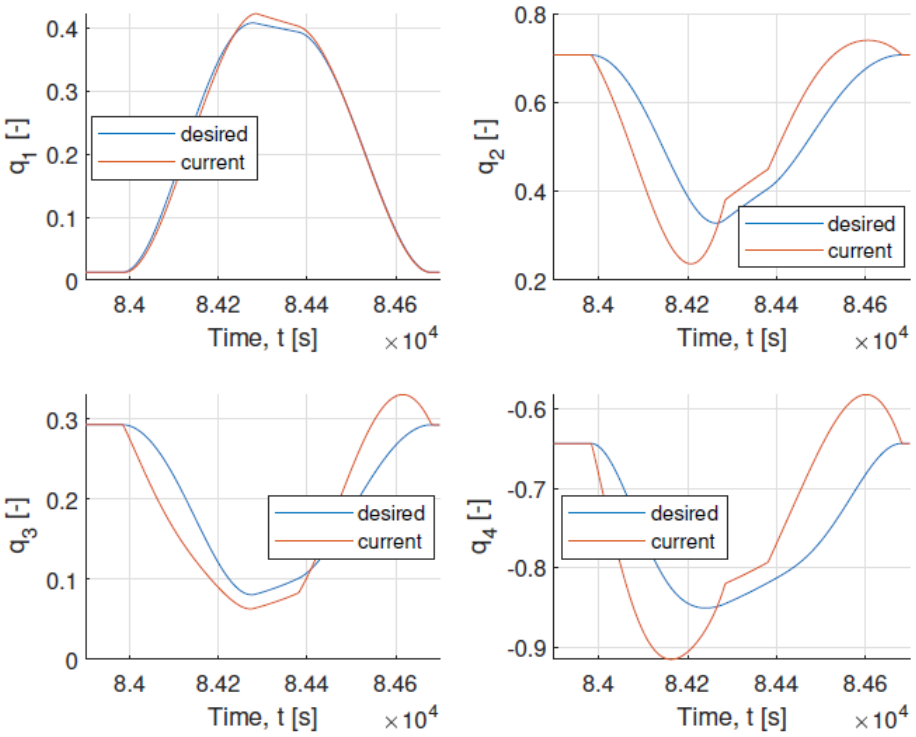


CURRENT WORK II – Robust Attitude Control & Failure Analysis

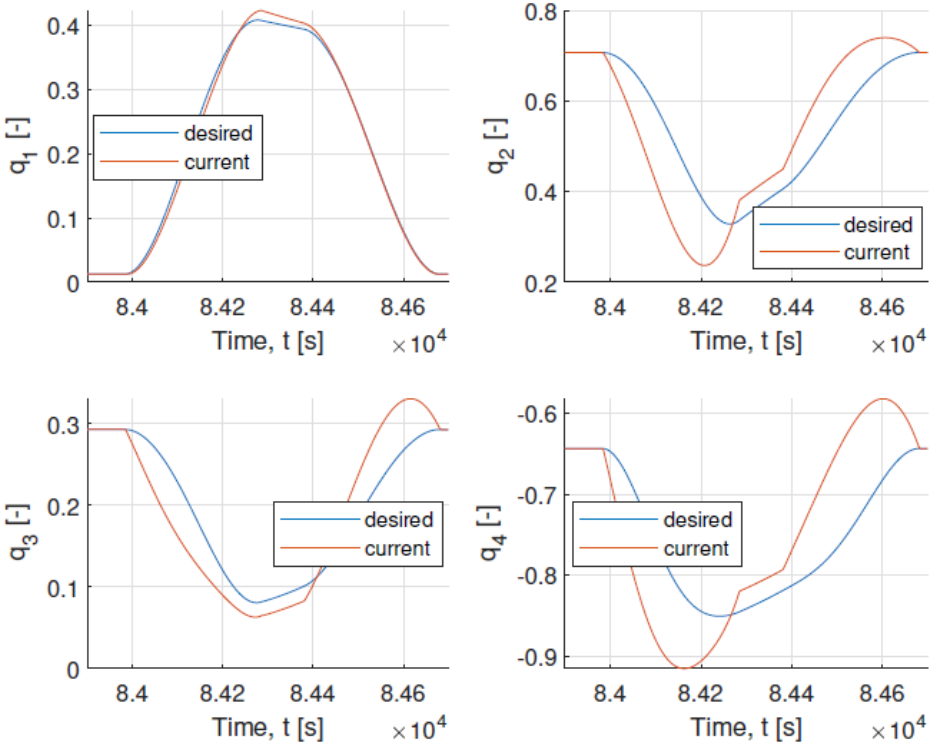
- **Simulation results**

1st Reaction wheel failed





No failure: Quaternions



1st RW failure: Quaternions

FUNDING SOURCES

- **PI**
  - Predictive guidance and control of NASA Astrobee robots in the International Space Station funded by NASA EPSCoR, New Mexico Space Grant Consortium
    - Collaboration with NASA Ames Research Center

- **Co-PI**
  - Space virtual telescope for X-ray observation (VTXO) sponsored by NASA
    - Formation flying of two small satellites for virtual telescoping
    - Work with NASA Goddard Space Flight Center
  - Satellite alignment system satellite (SAS-SAT) project funded by Northrop Grumman
    - Autonomous alignment and navigation through an optical relative alignment
    - Launch two sets of two CubeSats

RESEARCH NEEDS

- Mission scenarios for advancing resilience for space systems
- Onboard real-time guidance and control requirements
- Possible topics for collaboration