Using Robots for Advanced Rendezvous and Docking Simulation

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Overview

- Motivation
- Rendezvous and Docking (RvD) Simulator – EPOS 2.0
- Applications

Motivation

On-Orbit Servicing Missions

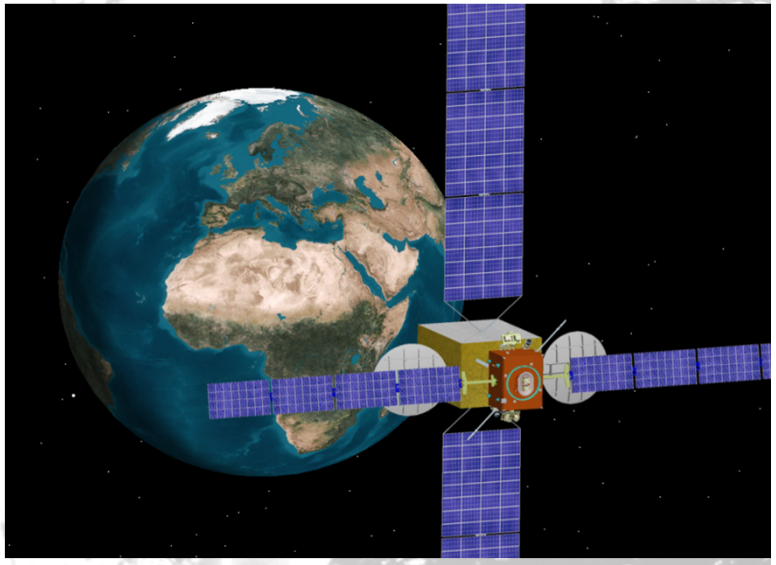
Objectives:

- Life time extension
- Repair, maintenance and assembly tasks
- Refueling
- Fleet management
- Disposal of space debris

Technological Challenges:

- Rendezvous and Docking in space with uncooperative targets

OOS Reference Missions

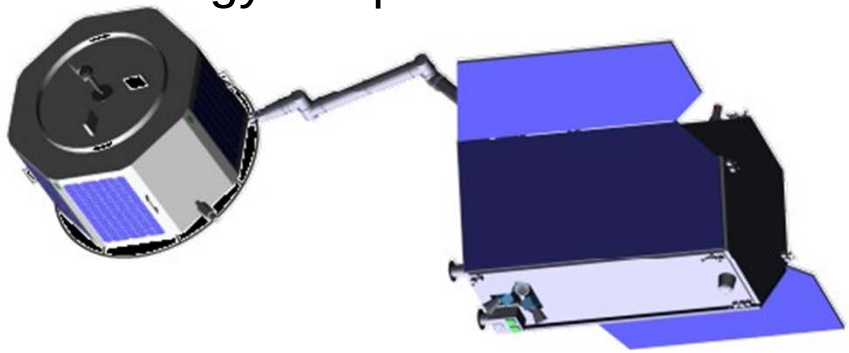


OLEV –
Orbital Lifetime Extension Vehicle

- Docking at an high value, geostationary communication satellites and take over attitude and orbit control

DEOS –
DEutsche Orbitale Servicing Mission

- Demonstration of German OOS technology in Space



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Necessary New Technologies

-New GNC-Systems for Rendezvous Phase
- Sensors: Camera, LIDAR, Radar

-New Systems for Docking and Berthing Phase
- New mechanisms for docking and grasping

-Degree of Grad Autonomy
- Ground-in-the-loop needs telepresence operations

-Extended Simulation Capabilities

Rendezvous and Docking Simulator EPOS 2.0

RvD Simulation Experience

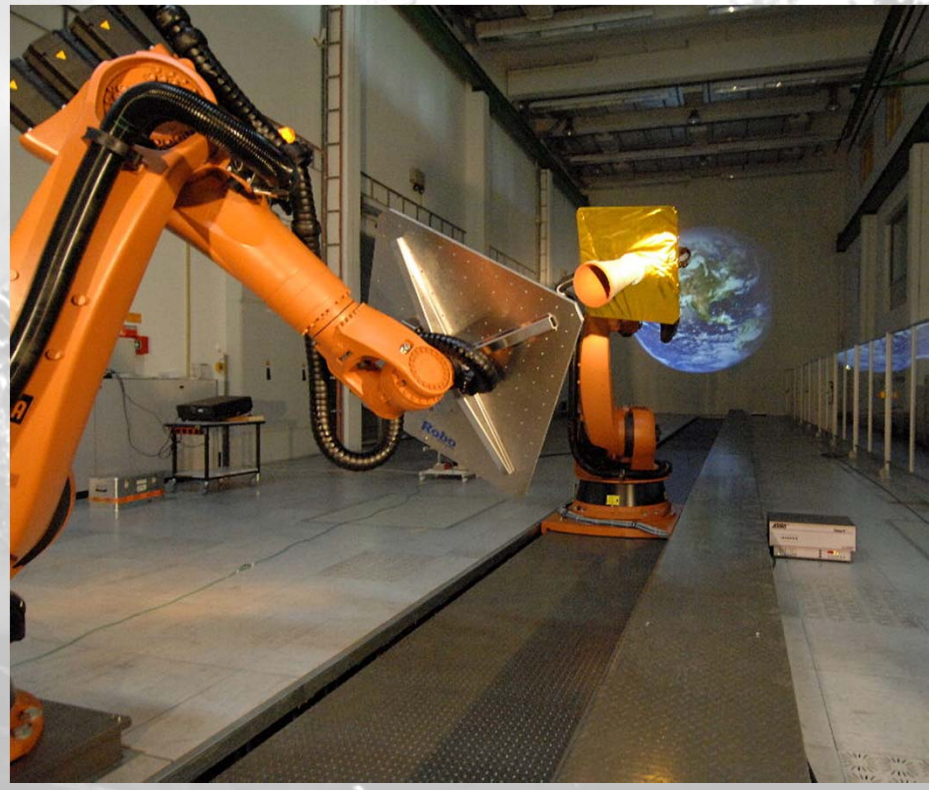
RvD Simulation Facility EPOS (1985 – 2006)
EPOS – European **P**roximity **O**perations **S**imulator

Projects:

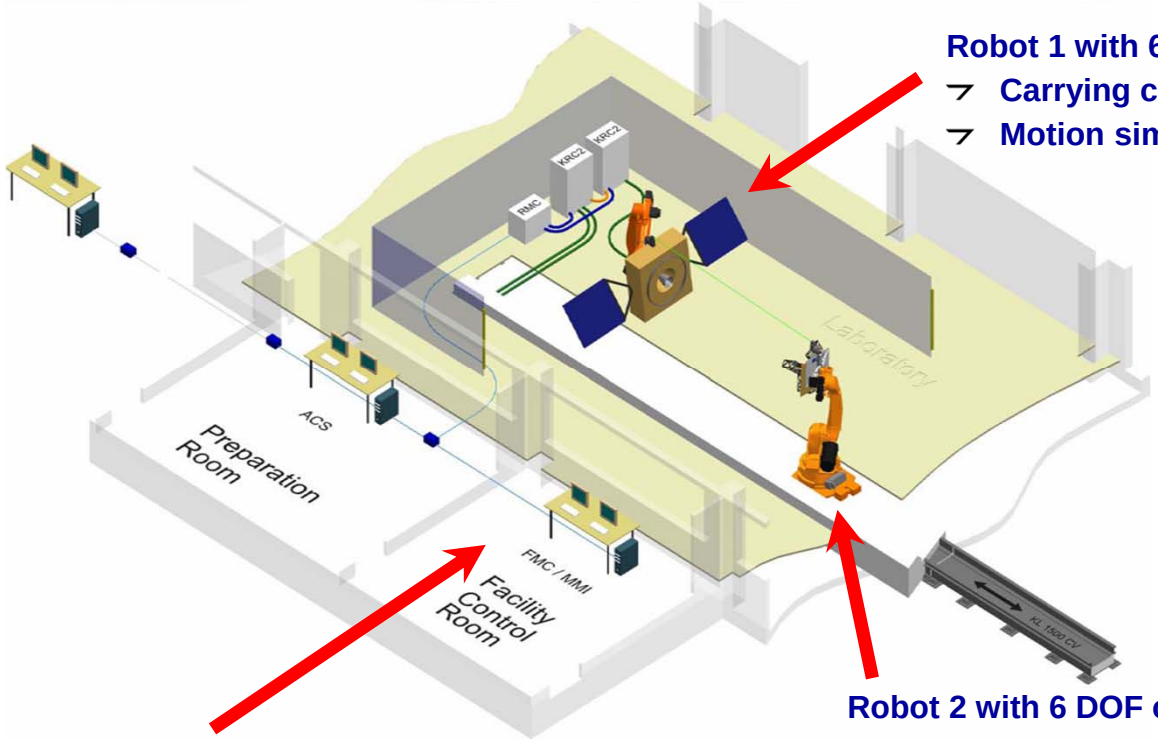
- Comparative sensor tests (MATRA/Saab/MBB, 1991)
- ARP tests (ESA, 1997 -1999)
- EDISON (EU, 1998 – 2000, distributed simulation over ATM network)
- ATV-Sensor tests (ESA, 2001-2006)
- HTV-Sensor tests (Japan/DJO, 2003-2007)

The New RvD Facilty - EPOS 2.0 Objectives

- Simulation of spacecraft rendezvous from 25 m to docking
- Simulation of contact dynamics during docking and berthing process
- realistic simulation of environmental conditions (e.g. Sun illumination effects)
- Hardware-in-the-loop simulator
- Calibrated test bed to use it for validation and verification of real flight h/w



Design Concept



Robot 1 with 6 DOF

- Carrying client satellite mock-up
- Motion simulation of client satellite

PC-based real-time facility control system

Robot 2 with 6 DOF on a 25 m rail system

- Carrying RV sensors and docking system of servicing satellite
- Motion simulation of servicing satellite

Facility Control Concept

3 Levels

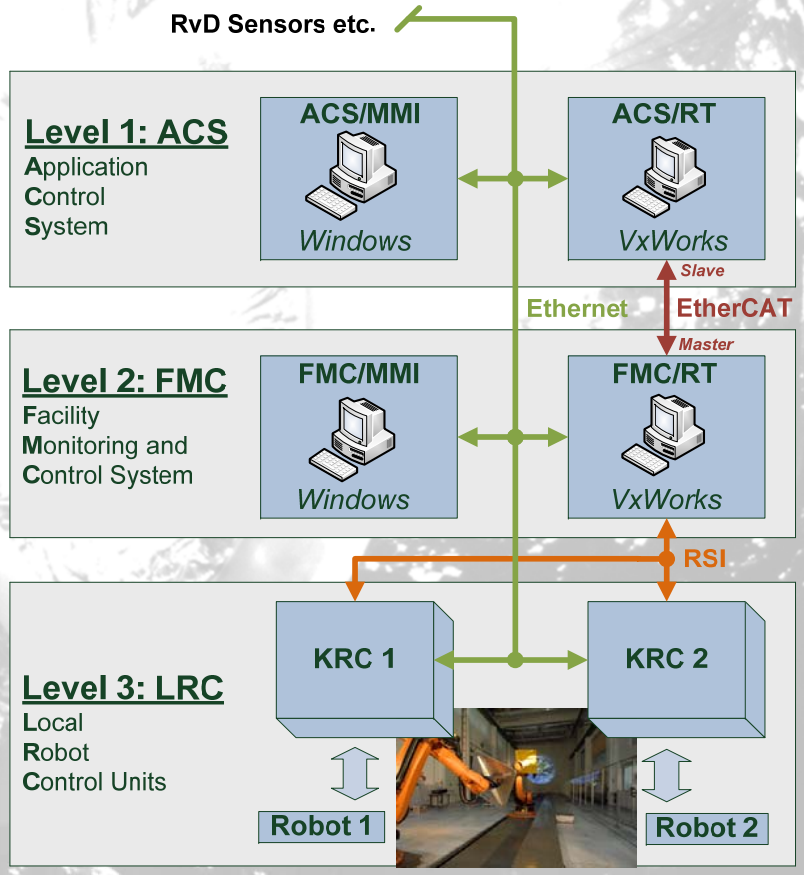
1. Application Control System (ACS)

   Simulation, preparation and analysis
2. Facility Monitoring and Control (FMC)

   Monitoring, operations and real-time control
3. Local Robot Control (LRC)

Interfaces:

- EtherCAT for deterministic Commanding
- Ethernet for all other non-real-time data transfers

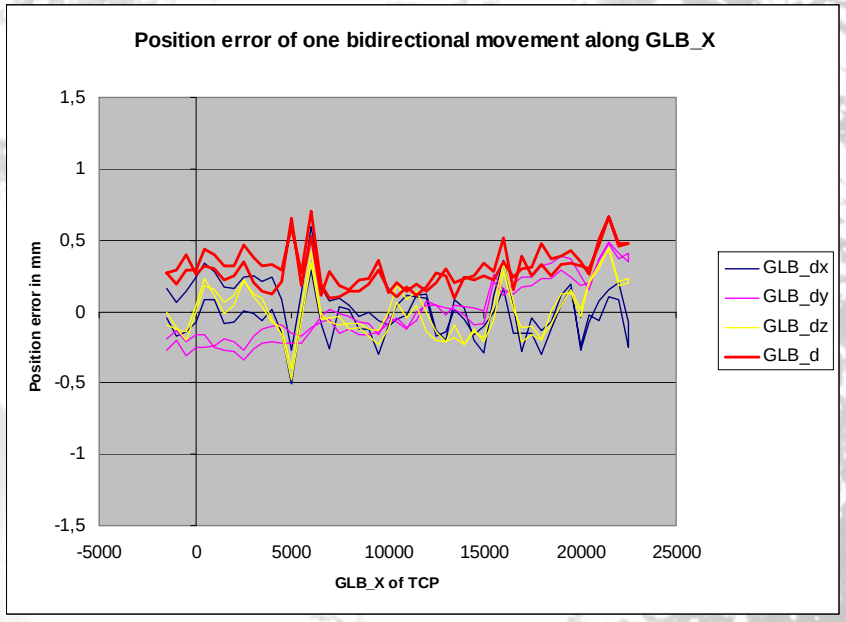


Capabilities and Performances

Parameter	Robot 1	Robot 2
Position:		
X	-2,5 - +24,5m	-2,5 - +2,5m
Y	-2,5 - +2,5m	-1,0 - +4,0m
Z	-0,5 - +1,5m	-0,5 - +1,2m
Roll	-300 - +300deg	
Pitch	-90 - +90deg	
Yaw	-90 - +90deg	
Velocity:	2m/s , 180deg/s	
Acceleration:	2.3m/s² , 100deg/s²	
Payload:	60kg	200kg
Command rate:	250Hz	

Position Accuracies

- Static calibration of all motion devices using Laser tracker
- 1.56mm / 0.20deg (3D/3σ)
- Installation of an Online Measurement System
  - Online correction by measured displacements
  - Accuracy will be increased by factor 10



Sun Illumination 1/2

Requirements:

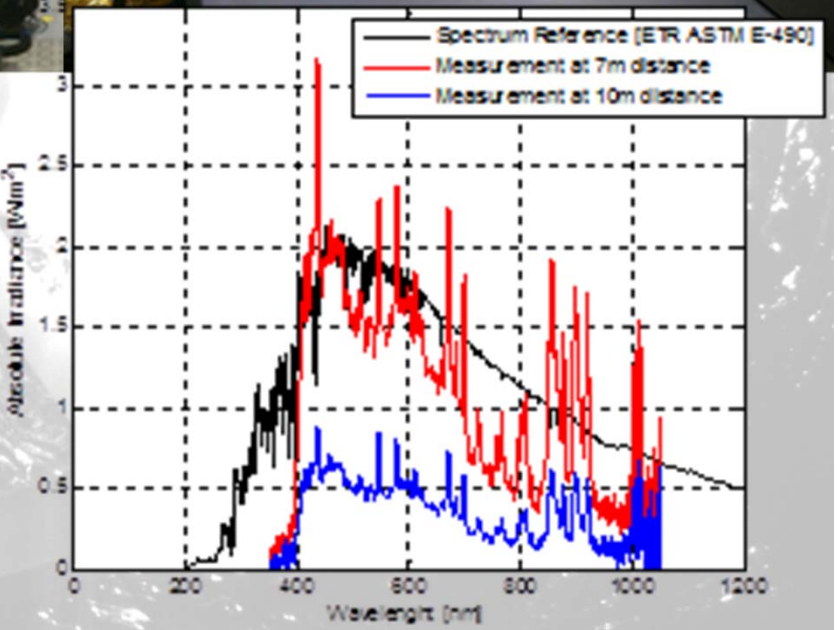
- Parallel light beam
- Diameter of illuminated target larger than 3m (real size S/C)
- Realistic Background
- Spectral power of 1,4kW/m²
- Spectral distribution like Sun

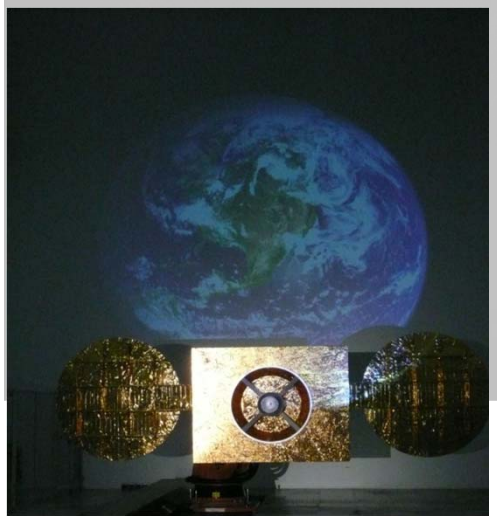
→ Technical and economical not feasible

Sun Illumination 2/2

Sun Illumination:
Using powerful studio floodlight ARRIMax18/12

- Input power 12kW
- halogen-metal vapour discharge lamp
- Smallest possible beam angle: 15deg
- Utmost realistic spectral distribution at close range (7m)





Background :

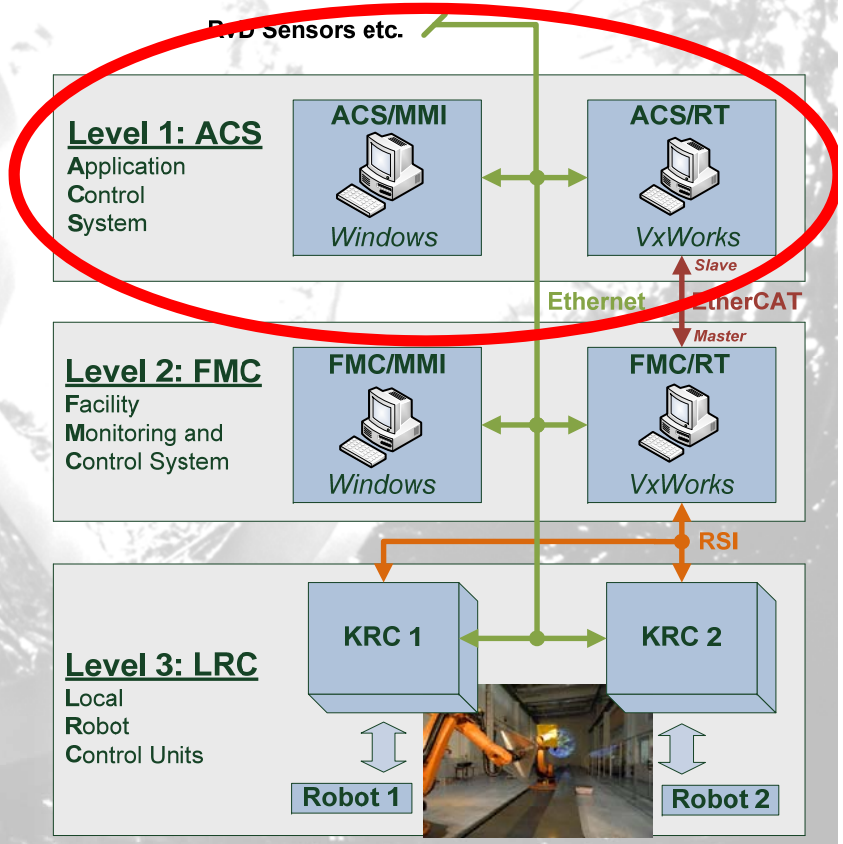
- Using high power beamer for background scene

Connecting to External Simulators 1/3

First Design Concept:

- Application has to be implemented on EPOS-ACS

- Problems:
  - customer simulations code has to be ported on EPOS-ACS.
    → incompatibilities with EPOS real-time OS VxWorks,
  - IF's to other hardware (e.g. onboard computer)
    → Interfaces has to be established on EPOS-ACS
  - Different sample frequencies (EPOS→ 250Hz / ext. Simulator 10Hz)



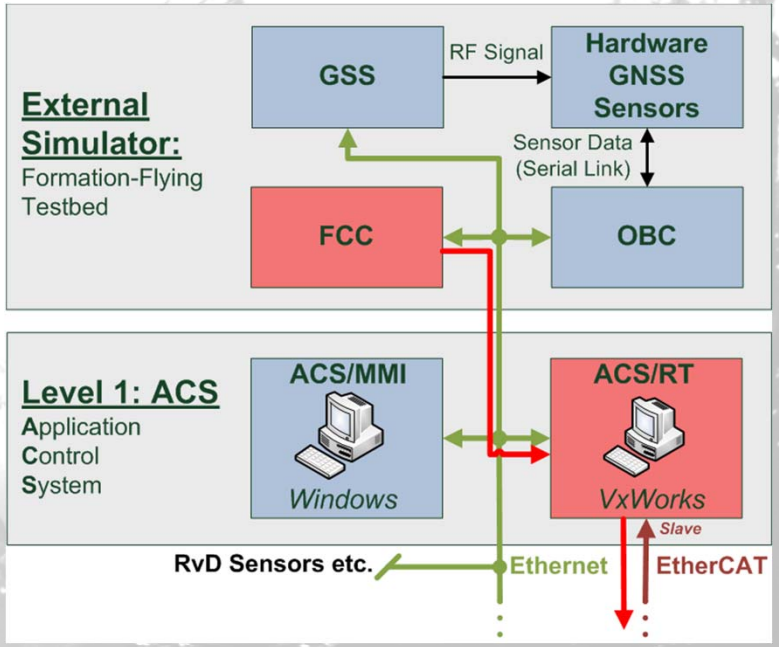
Connecting to External Simulators 2/3

- Ethernet Connection implemented in Matlab/Simulink using TCP/IP

- External Simulator:
  DLR's Formation Flying Testbed (used for PRISMA/TanDEM-X)

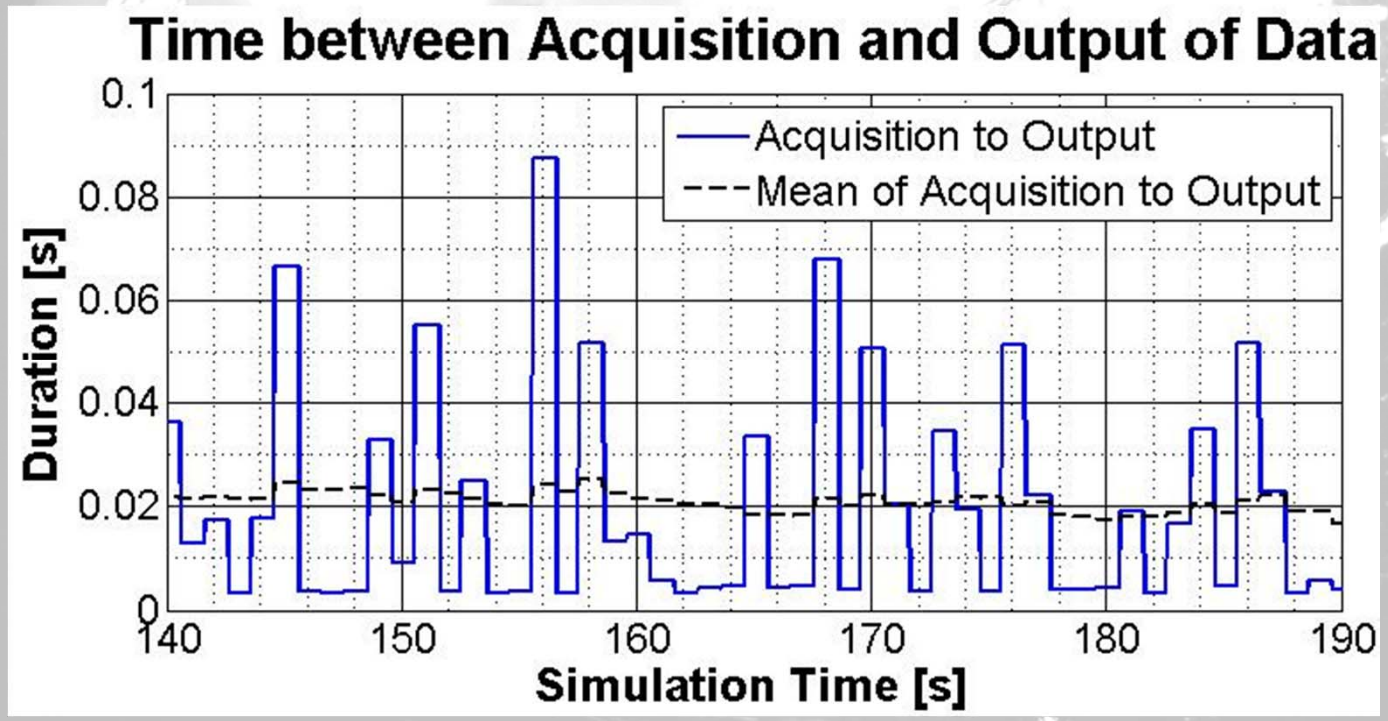
- Changes:
  External simulator:
    - Simulink IF model block to command trajectory to EPOS ACS

  EPOS-ACS:
    - IF's model block to receive commands
    - interpolation



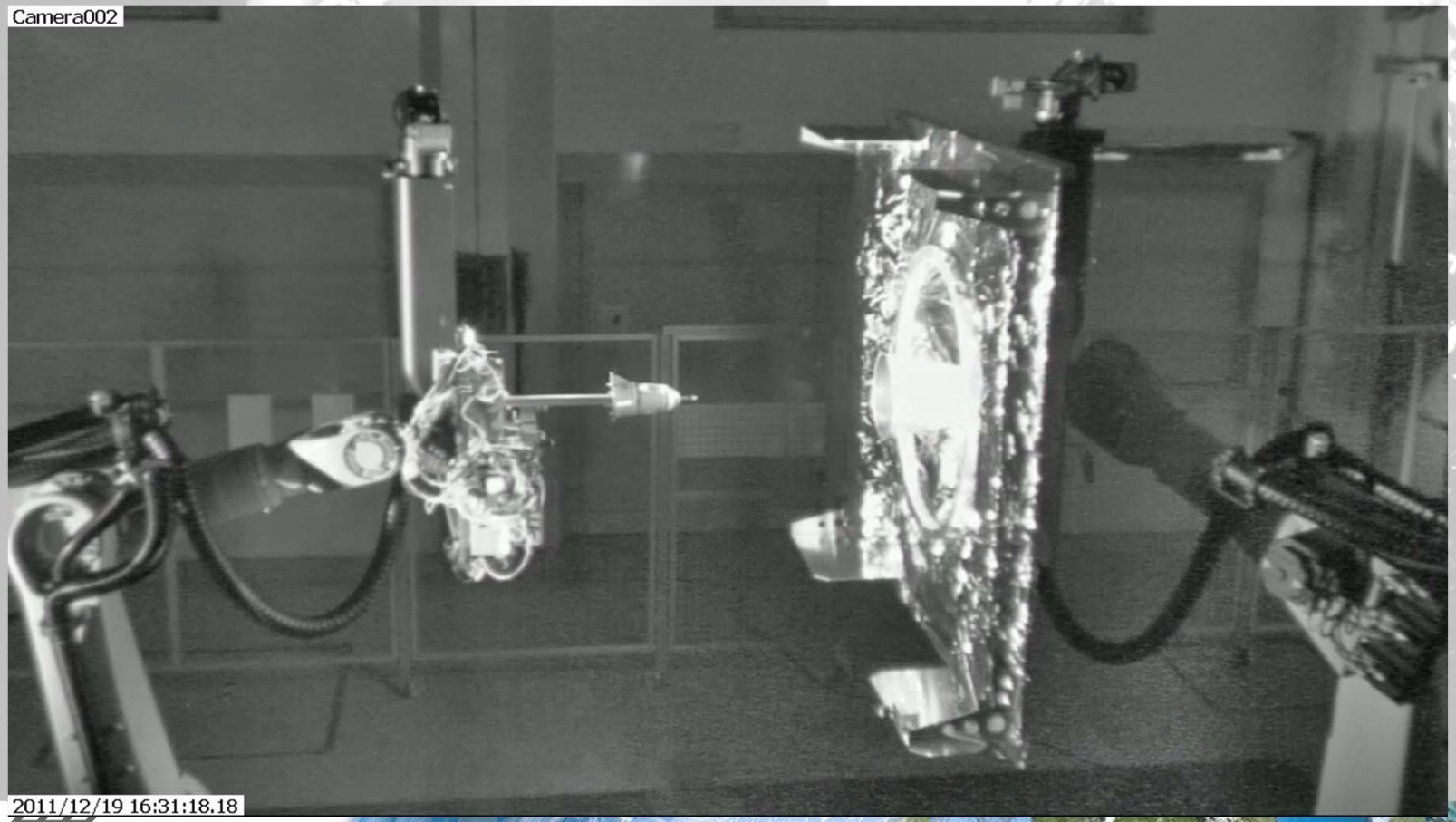
Connecting to External Simulators 3/3

Performance of expected Jitter-Delay:
Mean: 20ms
Maximum: <100ms

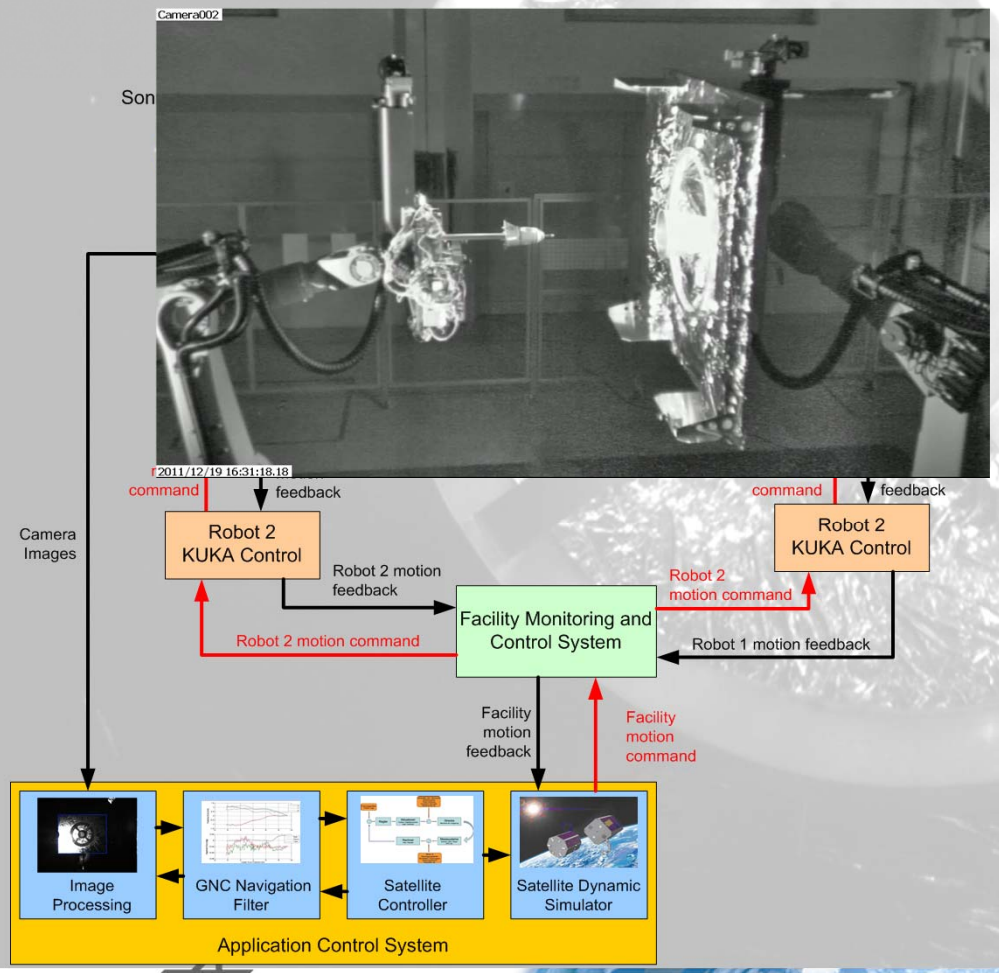


Applications

Rendezvous
HIL Simulation Concept
Typical hardware set up (VIBANASS-Project)



Rendezvous
Closed Loop Simulation 1/2



Objective:
Establish a HIL simulation containing all typical components represented in real h/w or in s/w

Concept:

- Target and RvD sensor/system mounted on the Robots
- Image processing, navigation filter, Controller and S/C dynamics implemented in s/w
- Robots representing the calculated trajectory

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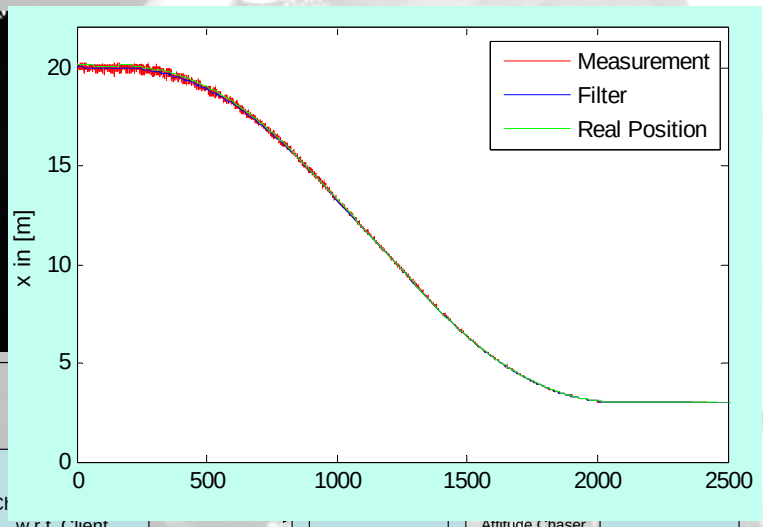
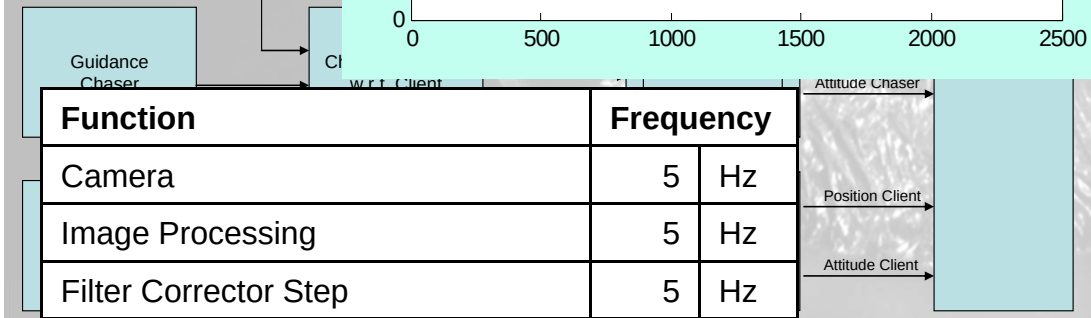
Rendezvous
Closed Loop Simulation 2/2





Function	Frequency	
Camera	5	Hz
Image Processing	5	Hz
Filter Corrector Step	5	Hz
Filter Propagation / Predictor Step	10	Hz
Controller	10	Hz
Satellite dynamics & kinematics	250	Hz

- Simulation development under Matlab/Simulink
- Using Matlab Realtime Workshop for Automatic code generation for VxWorks realtime OS
- Image processing using edge tracker algorithm
- Extended Kalman filter for smoothing the vision based measurements
- PID controller to follow guided trajectory
- Multitasking concept

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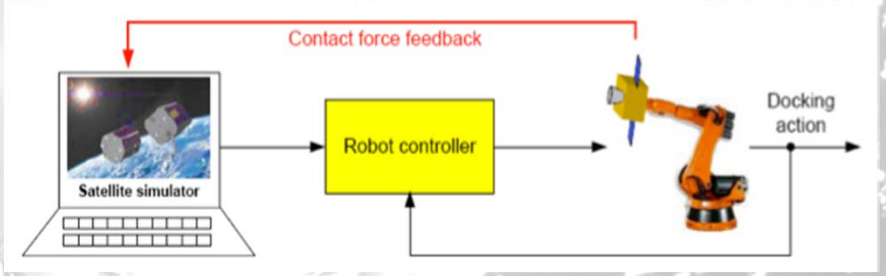
Docking simulation Concept

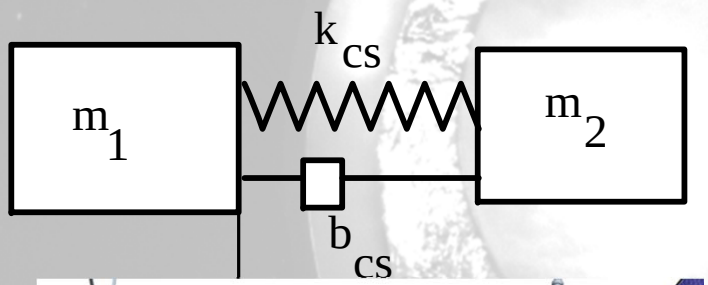
Simulation concept:

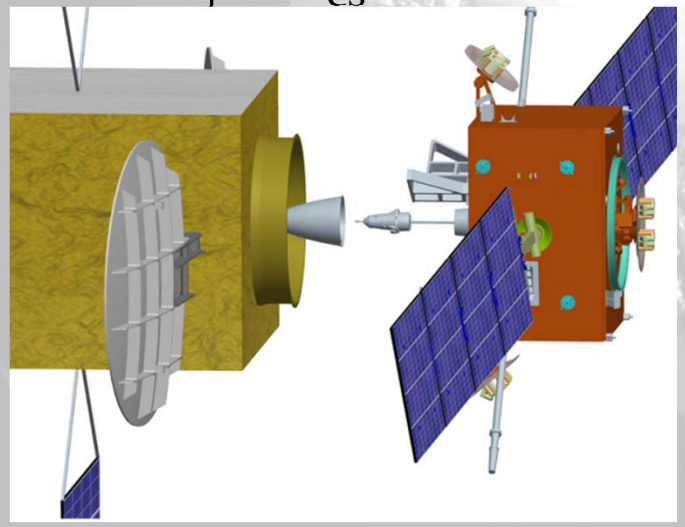
- Satellite simulator calculates dynamic response based on measured forces/torques
- Robots including the docking h/w follow calculated trajectory

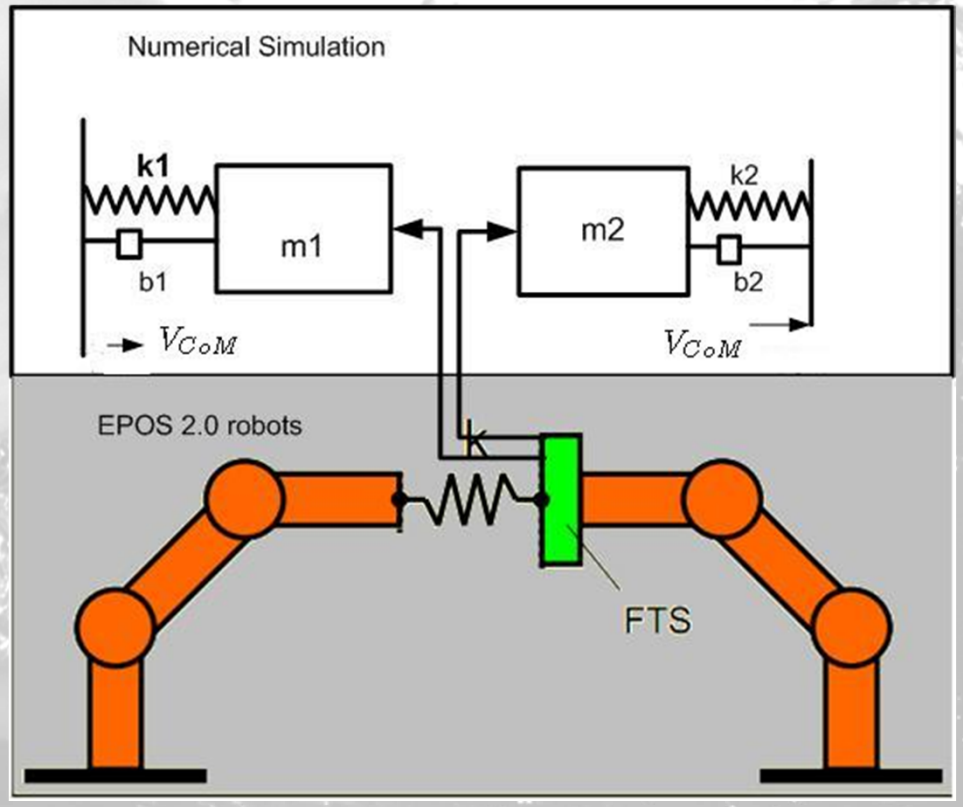


- Challenges:
  - To find space representative contact impedance model
  - Low bandwidth of the KUKA controller
  - High stiffness of EPOS 2.0 robots end-effectors (docking interfaces)
- Suggested method:
  - Hybrid contact model:
    - Combining the contact F/T data and virtual contact model.
    - Add passive compliance device
  - Active time-domain passivity control

Hybrid Contact Model



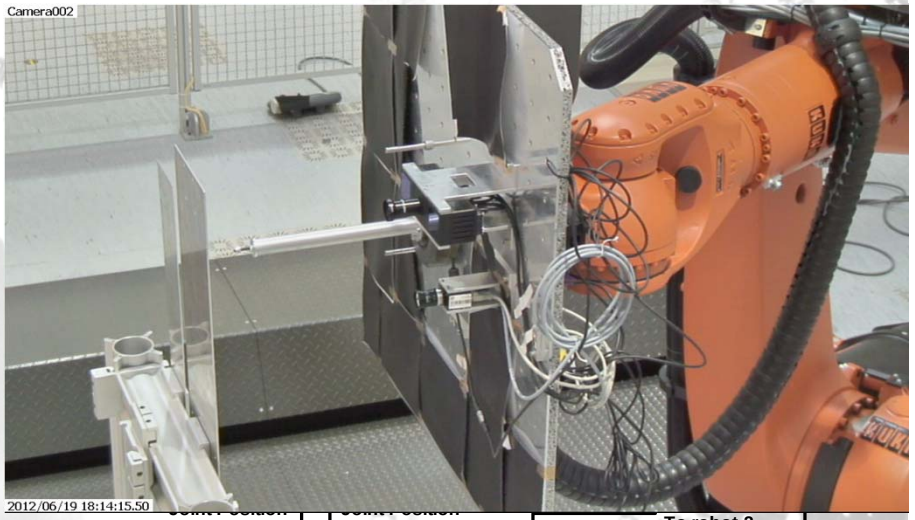


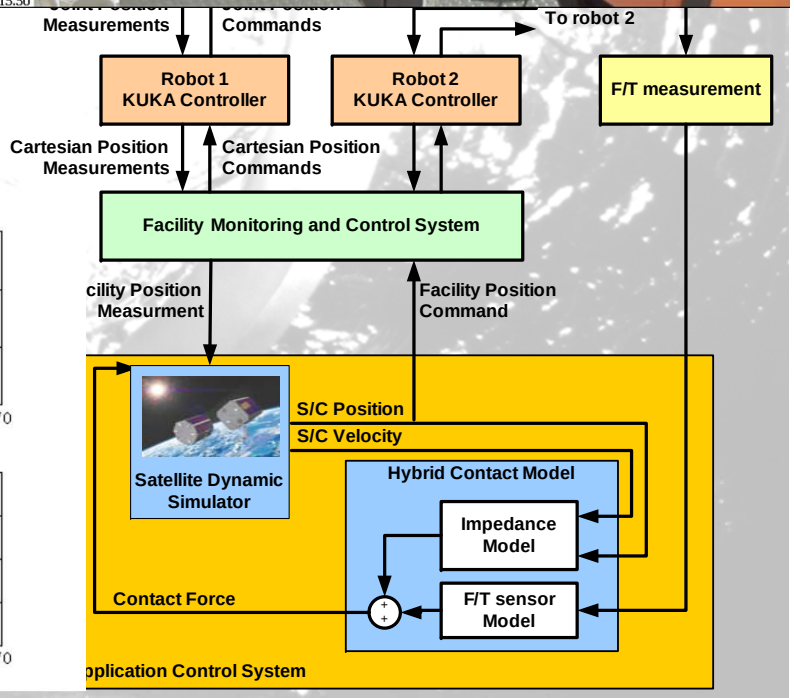


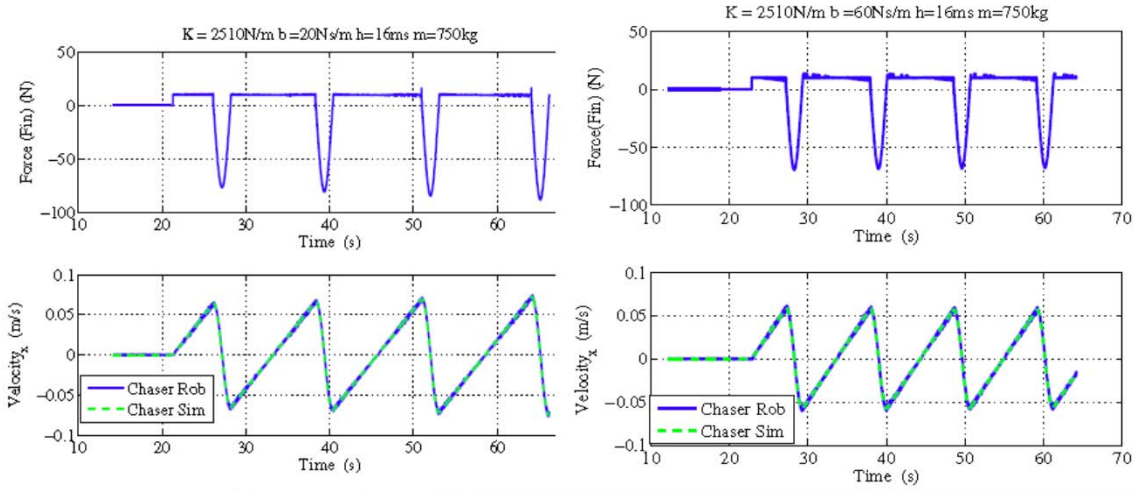
Experimental Results

Experiment setup:

- 1-DOF HIL simulation
- Masses: Chaser: 750kg
  Target: 10^6kg
- Cont. thruster force: 10N
- Initial velocity: 0.03m/s







Summary

- Presentation of capabilities and performances of Rendezvous and docking simulator EPOS 2.0

- Demonstration of HIL rendezvous simulation

- Demonstration of HIL docking simulation

Questions?