Development of On Orbit Assembly technologies to enable spacecraft servicing

Federico Basana - 37^{th} Cycle

Supervisor: Dr. Francesco Branz

Meeting - 05/09/2022

Outline

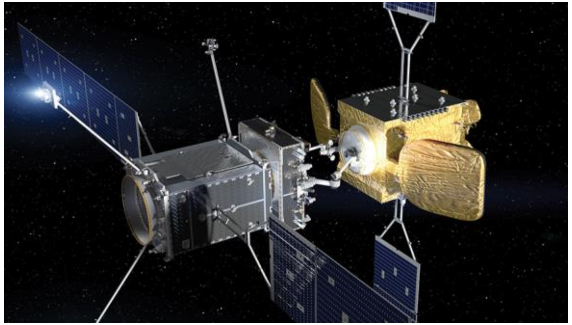
- Introduction
- Proposed mission
- Activities performed
    - Robotic arm minimum base reaction control
    - GNC and robotic arm coupled control
- Future work

On-Orbit Servicing (OOS):

- Non-contact support
- Orbit maintenance or modification
- Repair, assembly
- Refuelling and commodities replenishment
- Active Debris Removal

MEV-1

Orbital Express - DARPA



Outline

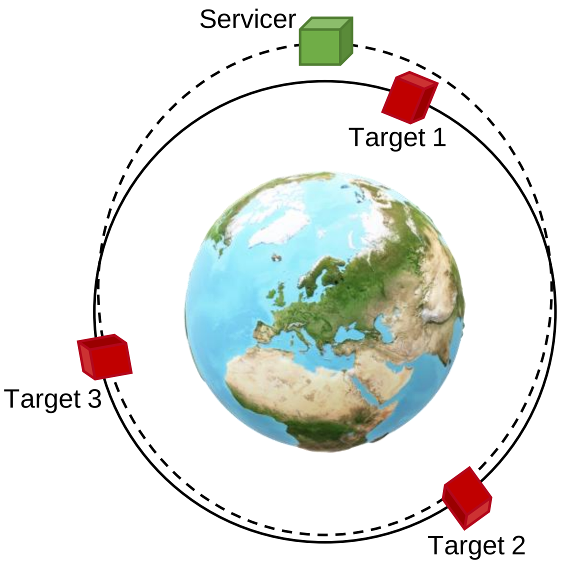
- Introduction
- Proposed mission
- Activities performed
  - Robotic arm minimum base reaction control
  - GNC and robotic arm coupled control
- Future work

Proposed mission

The problem:
Use a single spacecraft to deal with different servicing requests from satellites

The idea:
Equip a satellite (servicer) with several fundamental modules that answer to the different servicing requests of the target satellites.

Proposed mission



Identification of the targets that could benefit the most from OOS missions:

- Large GEO platforms
- Satellites of large constellation in LEO

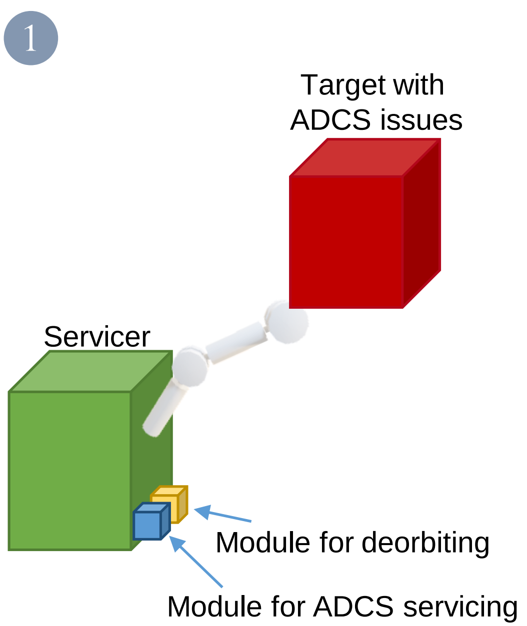
First challenge:

For the two selected orbital areas, study the orbital transfers for servicing multiple targets:

- Is it feasible?
- What is the ΔV required?

Proposed mission

After the rendezvous manoeuvre the servicer starts the Close Proximity Operations to service the target



Proposed mission

Second challenge:

Manoeuvring space manipulators:

- Decoupled control → Minimum base reaction control
- GNC and robotic arm coupled control

Third challenge:

Design and test of the On Orbit Assembly fundamental modules

Outline

- Introduction
- Proposed mission
- Activities performed
  - Robotic arm minimum base reaction control
  - GNC and robotic arm coupled control
- Future work

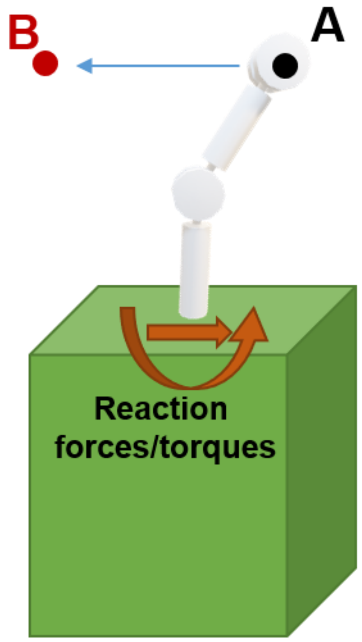
Minimum base reaction control

Manoeuvring space manipulators generates reaction torques at the base of the manipulator acting as spacecraft attitude disturbances.

A part of the research activity was dedicated at implementing an effective control of the end-effector pose capable of minimizing these attitude disturbances.

In the study an autonomous three-axes stabilized spacecraft equipped with a 7-DoF robotic arm is considered.

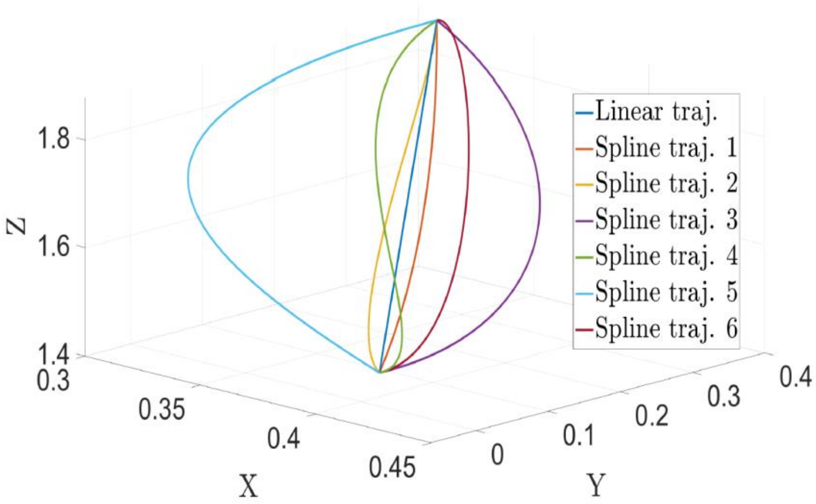
Two minimization methods are compared:
- kinetic energy minimization method (MKE)
- classical inverse kinematic method (IK)



Minimum base reaction control

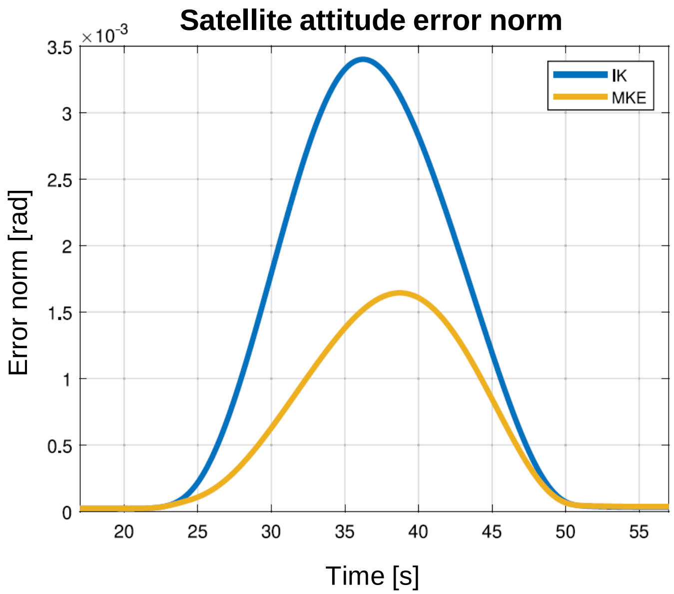
Seven different trajectories are considered in order to compare the performance of the two methods.

A Simulation Tool has been developed in the MATLAB/Simulink environment. It is capable of simulating the dynamics of a satellite equipped with a 7-DoF robotic arm during the target capture phase.



Minimum base reaction control

Trajectory	Mean EE attitude error [%]	Mean EE position error [%]	Mean satellite attitude error [%]	Mean torque required [%]
Linear	-11	-39	-22	-19
Spline 1	-5	-46	-29	-25
Spline 2	-14	-47	-30	-26
Spline 3	-55	-58	-17	-19
Spline 4	-9	-50	-27	-9
Spline 5	-32	-47	-15	-4
Spline 6	-43	-59	-22	-13



By reducing the disturbances on the satellite attitude generated by the robotic arm during its manoeuvre, the MKE method has a beneficial effect on the robotic arm performance.

Outline

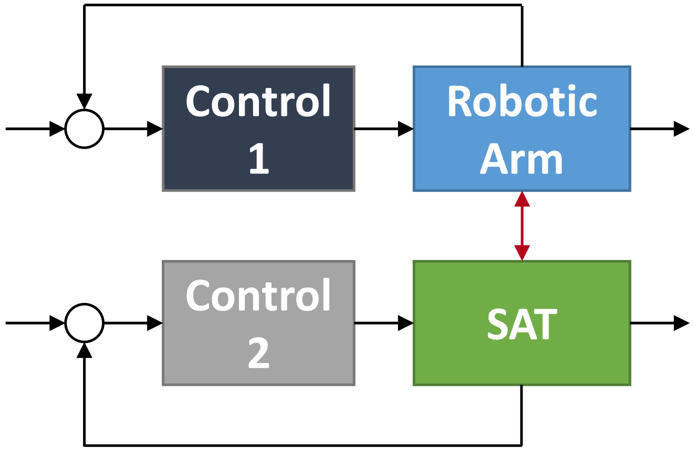
- Introduction
- Proposed mission
- Activities performed
    - Robotic arm minimum base reaction control
    - GNC and robotic arm coupled control
- Future work

GNC and robotic arm coupled control

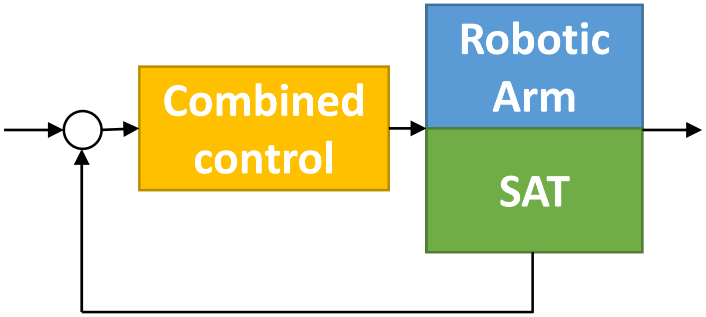
An alternative to the decoupled control is the combined control strategy.

The chaser satellite actuators and the robotic arm joint are seen as multiple degrees of freedom of the same control plant.

Decoupled control



Combined control



GNC and robotic arm coupled control

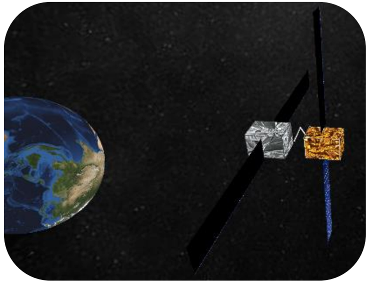
A research activity has been conducted aiming at developing the Navigation and Control subsystems of a GNC system for controlling a chaser equipped with a redundant manipulator.

ESA contract

- UNIPD - CISAS ← Functional Engineering Simulator (FES)
- POLIMI - DAER ← Guidance and Control algorithm
- UNINA - DII ← Navigation algorithm

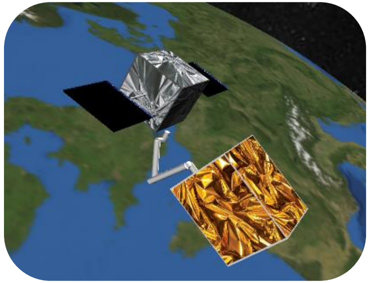
GNC and robotic arm coupled control

Scenario 1



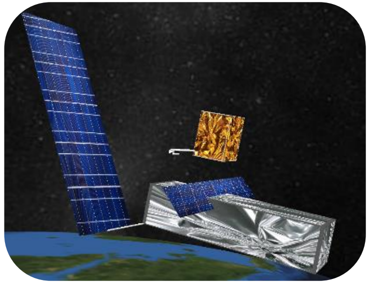
The target (large telecom satellite) is assumed to be operative, controllable and capable to receive a refuel/update/repair by the servicing satellite.

Scenario 2



The target (One web Arrow platform) is considered prepared for servicing: it is equipped with a grapple fixture and fiducial markers across the spacecraft body to aid the navigation function.

Scenario 3



The capture of a large space debris (ENVISAT) is considered. The chaser is synchronized with the motion of the non-cooperative target which is considered spinning at a rate of 5 deg/s.

In all the scenarios, the capture and the post-capture stiffening of the robotic arm phases are considered

GNC and robotic arm coupled control

A numerical simulation tool called Functional Engineering Simulator (FES) is developed in the MATLAB/Simulink environment to test and validate the Control and Navigation functions.

The FES implements:

- simplified models of the servicer and target satellite
- environmental disturbances (e.g. atmospheric drag, geomagnetic field, gravity gradient)
- propellant sloshing
- real actuators and sensors behaviour

Three different tests have been conducted to investigate the GNC system performance:

1. nominal simulations
2. error budget analysis
3. preliminary Monte-Carlo analysis

GNC and robotic arm coupled control

Nominal simulations

Scenario 1	Position error norm [mm]	5
	Attitude error norm [deg]	0.06
Scenario 2	Position error norm [mm]	10
	Attitude error norm [deg]	0.3
Scenario 3	Position error norm [mm]	60
	Attitude error norm [deg]	0.2

*The reported results refer to the final instant of the simulation

Error Budget analysis
allowed to determine the contribution of each error source to the overall control error

Preliminary Monte Carlo analysis
assessed the robustness of the developed GNC system

Outline

- Introduction
- Proposed mission
- Activities performed
  - Robotic arm minimum base reaction control
  - GNC and robotic arm coupled control
- Future work

Future work

Future works includes:

1. Study of the orbital transfers of multiple targets servicing mission
2. Preliminary design of the fundamental modules
3. Experimental test of Close Proximity Operations

Thanks for the attention

800 ANNI 1222 · 2022

UNIVERSITÀ DEGLI STUDI DI PADOVA