University of Padova
PhD course in
Science, Technologies and Measurements for Space

Design and development of a mechanical rendezvous interface for satellites capture

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Outline

1. Brief recap
2. Improve the facility
3. Test the system behavior
4. Kinematic simulation
5. Capture interface
6. Conclusions and future work

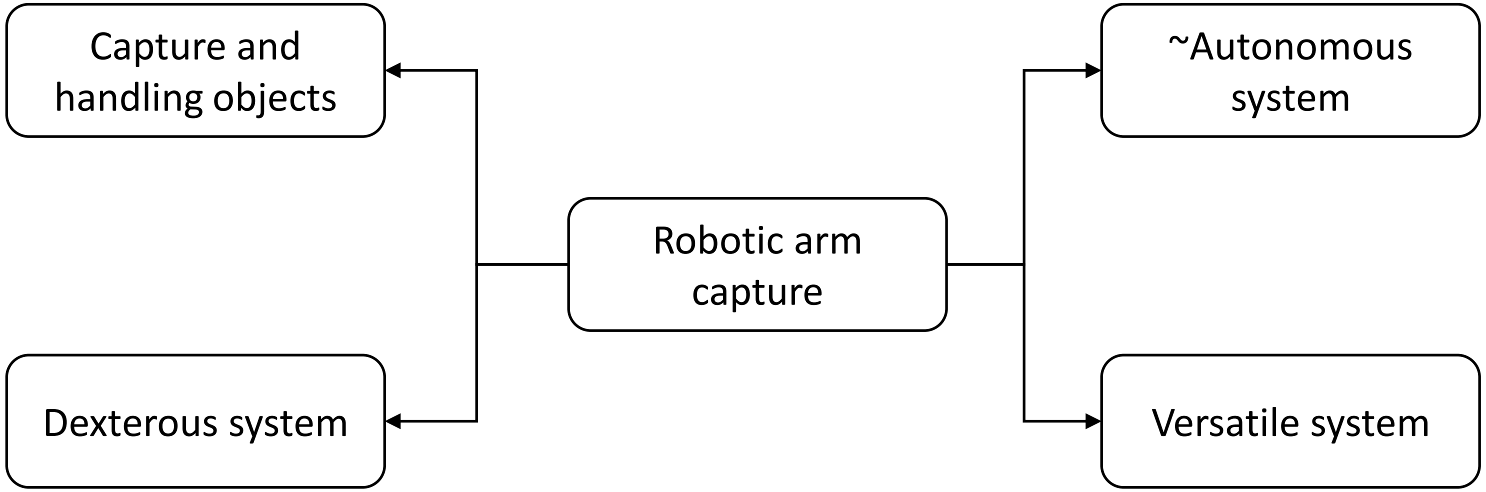
1. Brief recap: robotic space capture

Refueling (rendering)

On Orbit Servicing allows a variety of operations on orbiting satellites, such as:

- Refueling;
- Refurbishment;
- On-Orbit Assembly ;
- Active Defunct satellite Removal (space debris);
- …

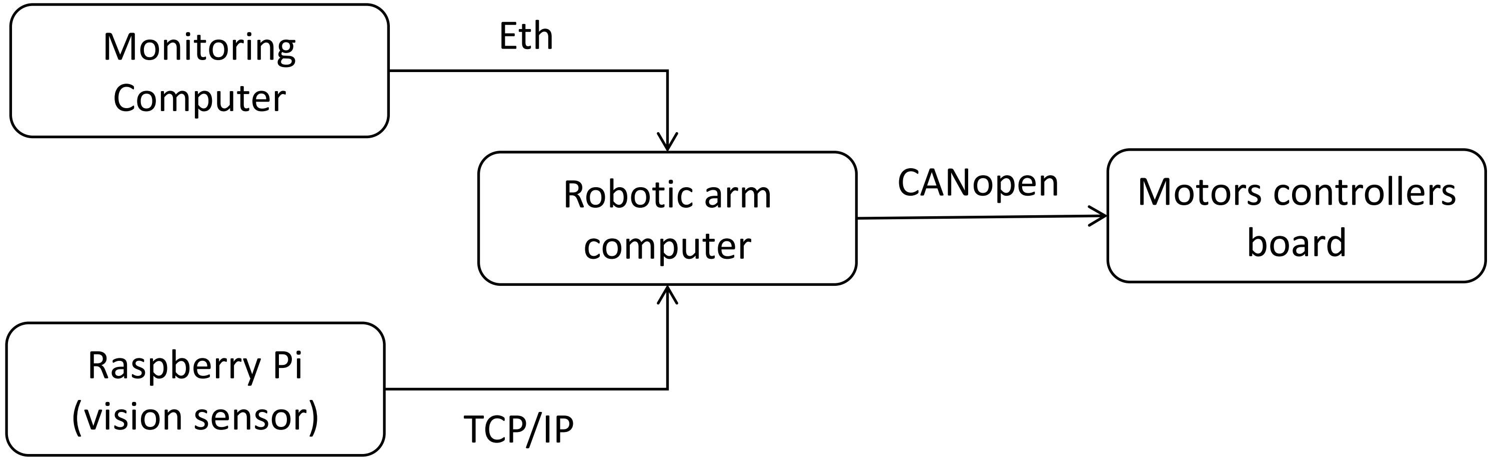
All OOS tasks require that a client satellite is properly captured by a servicer vehicle.

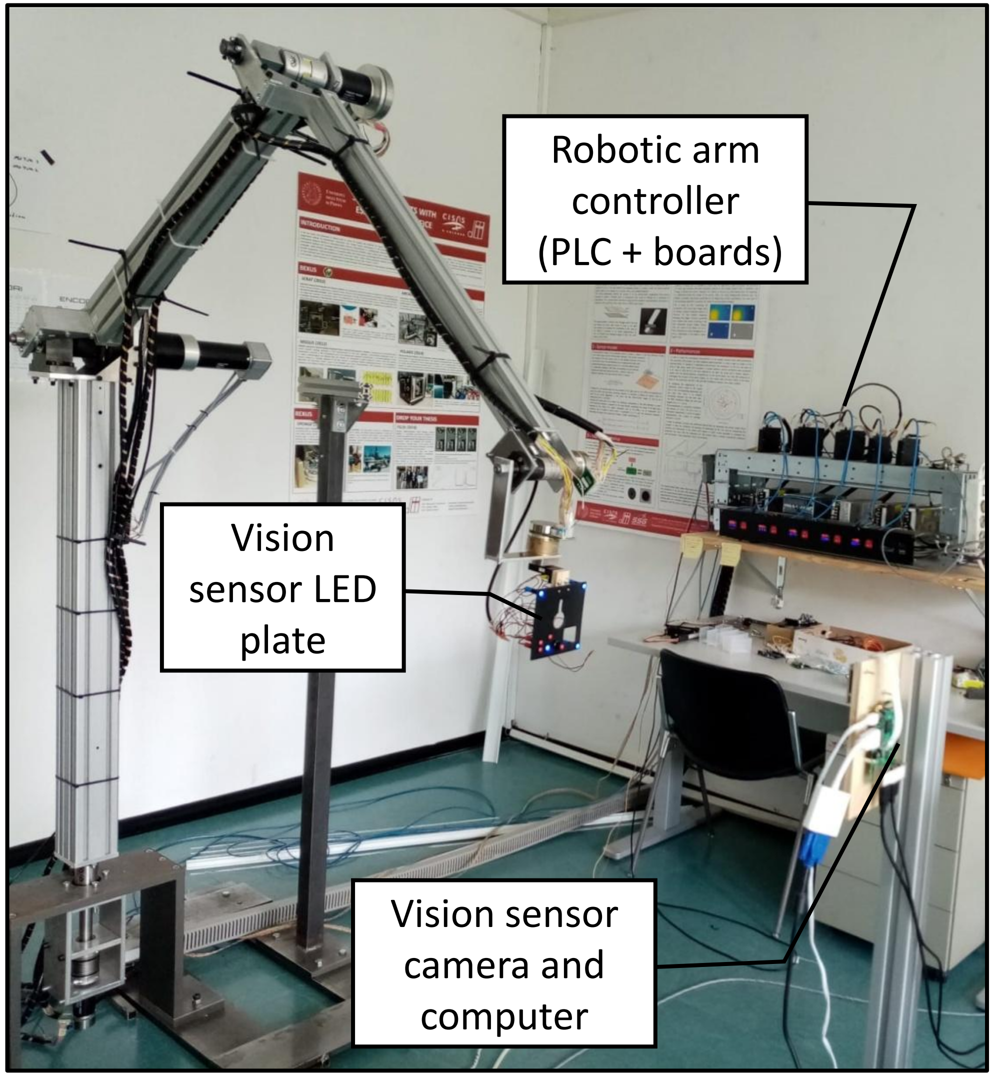


2. Improve the facility: Robot low level software

Low level software:

- Part of the software that manages the robotic arm;
- Main tasks:
  - Solve the inverse kinematics,
  - Control the robot joints,
  - Communicate with other subsystems (e.g.: the navigation subsystem).





2. Improve the facility: integration of the navigation sensor

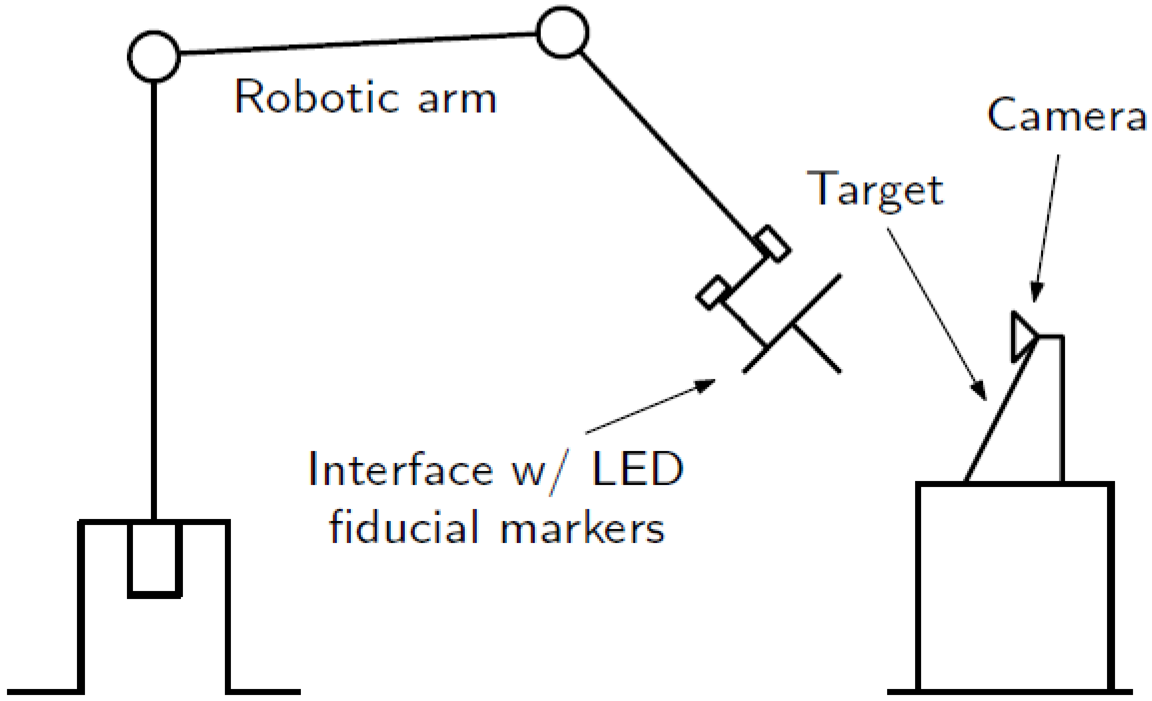
Robotic arm

- 6 Dof positioning system.
- Needed for an "external" navigation sensor.

Vision system

- **Small satellite** – scale sensor (small dimensions, limited power, …).
- Composed by two parts: camera and LED plate. The first reconstructs the pose of the second.
- Already tested in 3-DoF: two translations and one rotation.

We have performed several experiments to evaluate the joint operations of the robotic arm & the vision system



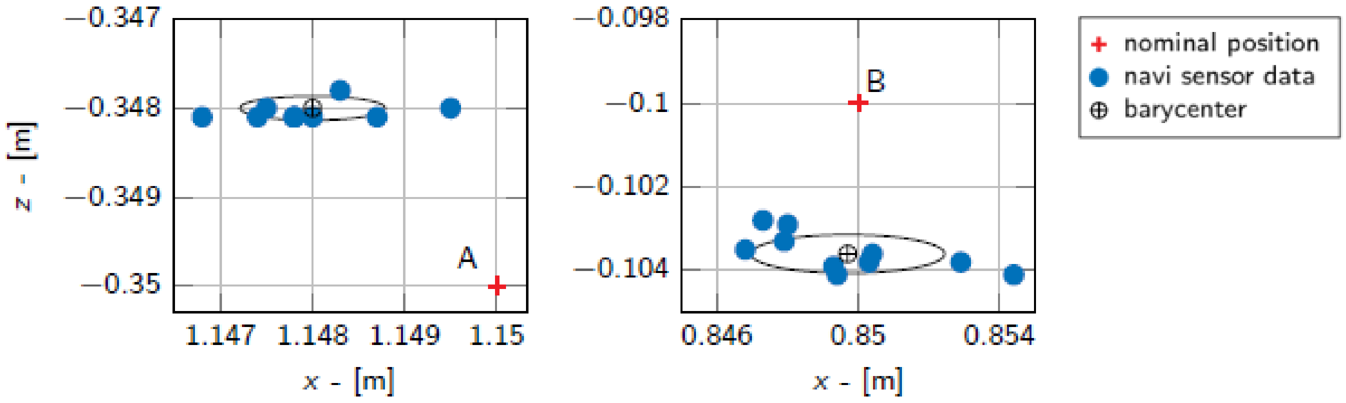
3. Test the system behavior: static tests

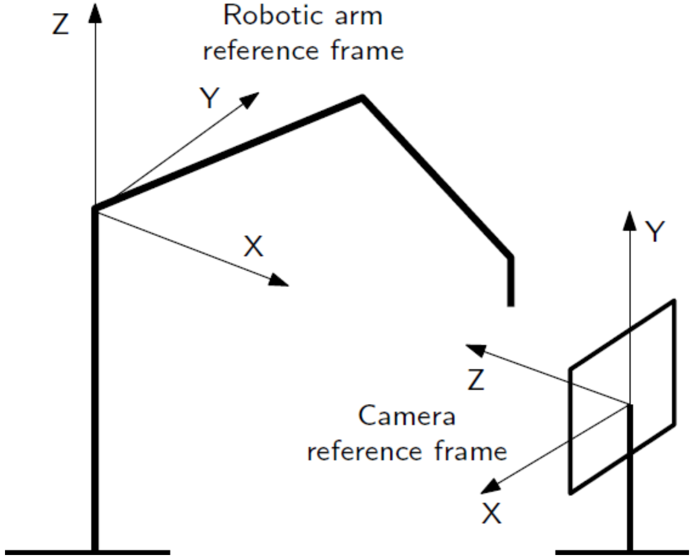
Static tests to evaluate system* accuracy and repeatability:

- Carried out by placing the end-effector in two points several times.
- One image taken at each point.
- Accuracy of 4.5mm to 5.5mm due to the robot.
- Repeatability of 0.7mm to 2.4mm due to the camera.
- The accuracy error is due to the model of the inverse kinematics that does not include the manufactory and assembly errors.

Point ID	Accuracy [mm]	Repeatability [mm]
A	4.5	0.7
B	5.5	2.4

Accuracy and repeatability at each point (1σ)



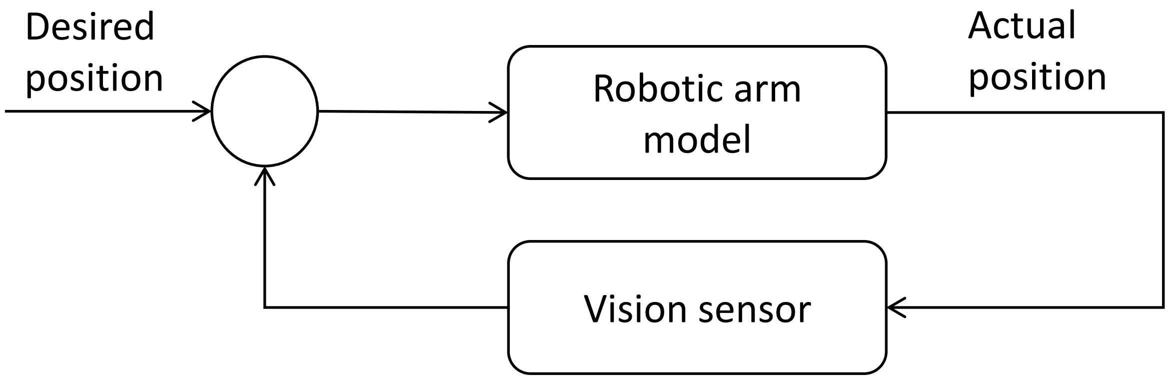


*System = robotic arm + visions sensor

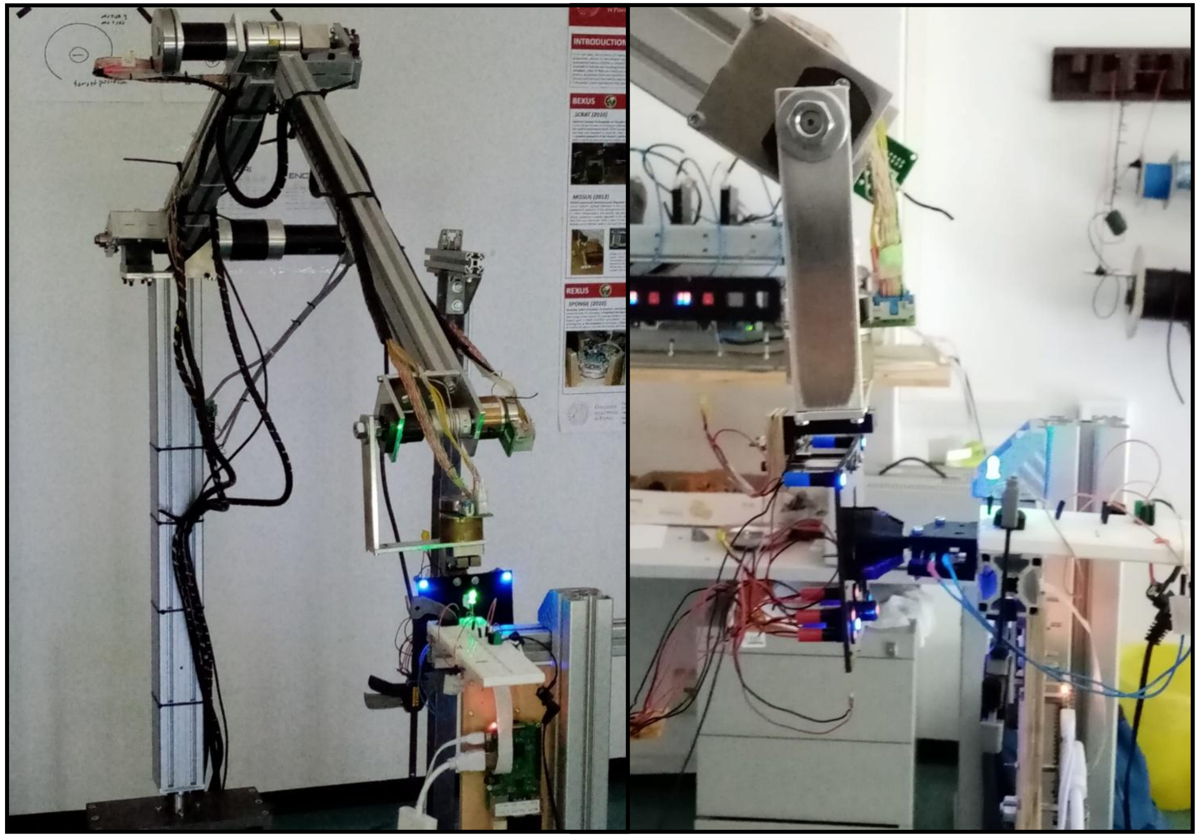
3. Test the system behavior: accuracy improvement

Accuracy improvement

- The camera was placed into the robot control loop to compensate the accuracy error (close loop).

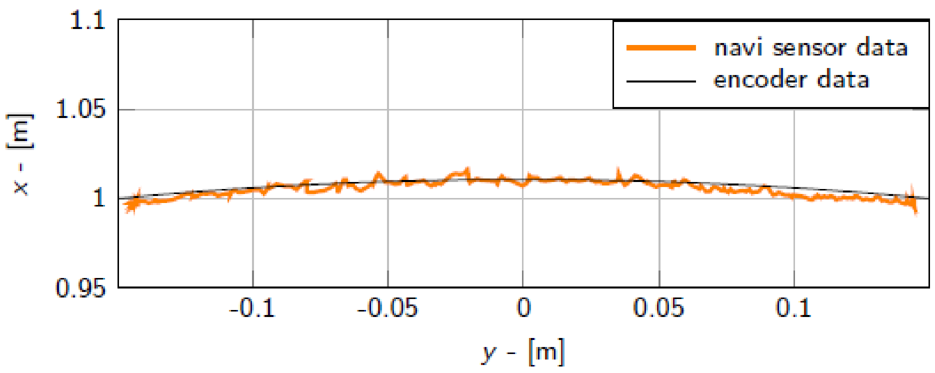


- This gave us the possibility to perform a accuracy test where the robotic arm pressed a switch which turned on a green LED

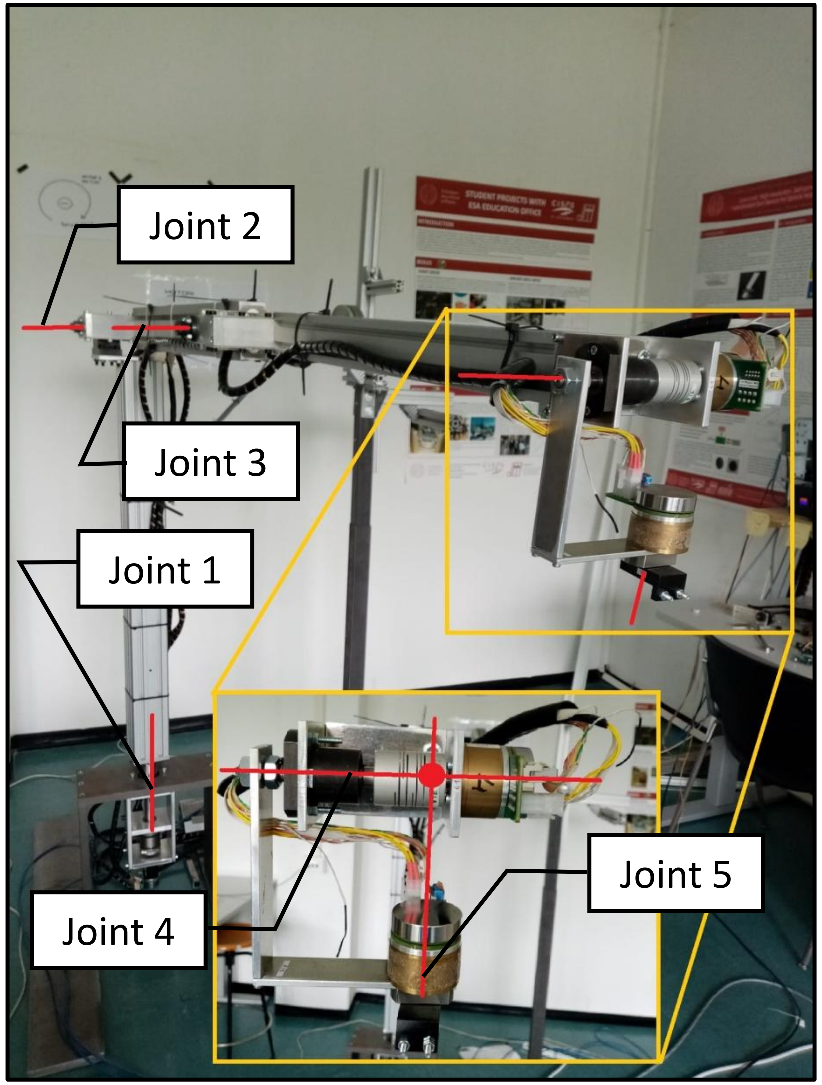


3. Test the system behavior: dynamic tests

Dynamic tests showed another important issue of the robotic arm: **vibrations**



Mean error [mm]	Std. deviation (1σ) [mm]
4.7	2.2



Many factors cause vibrations:

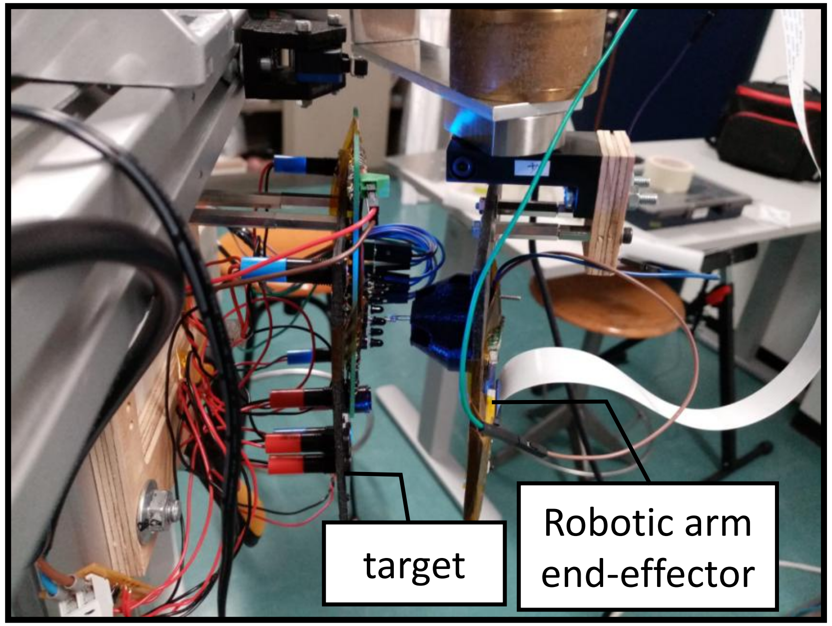
- link flexibility,
- joint flexibility,
- Backlashes,
- …

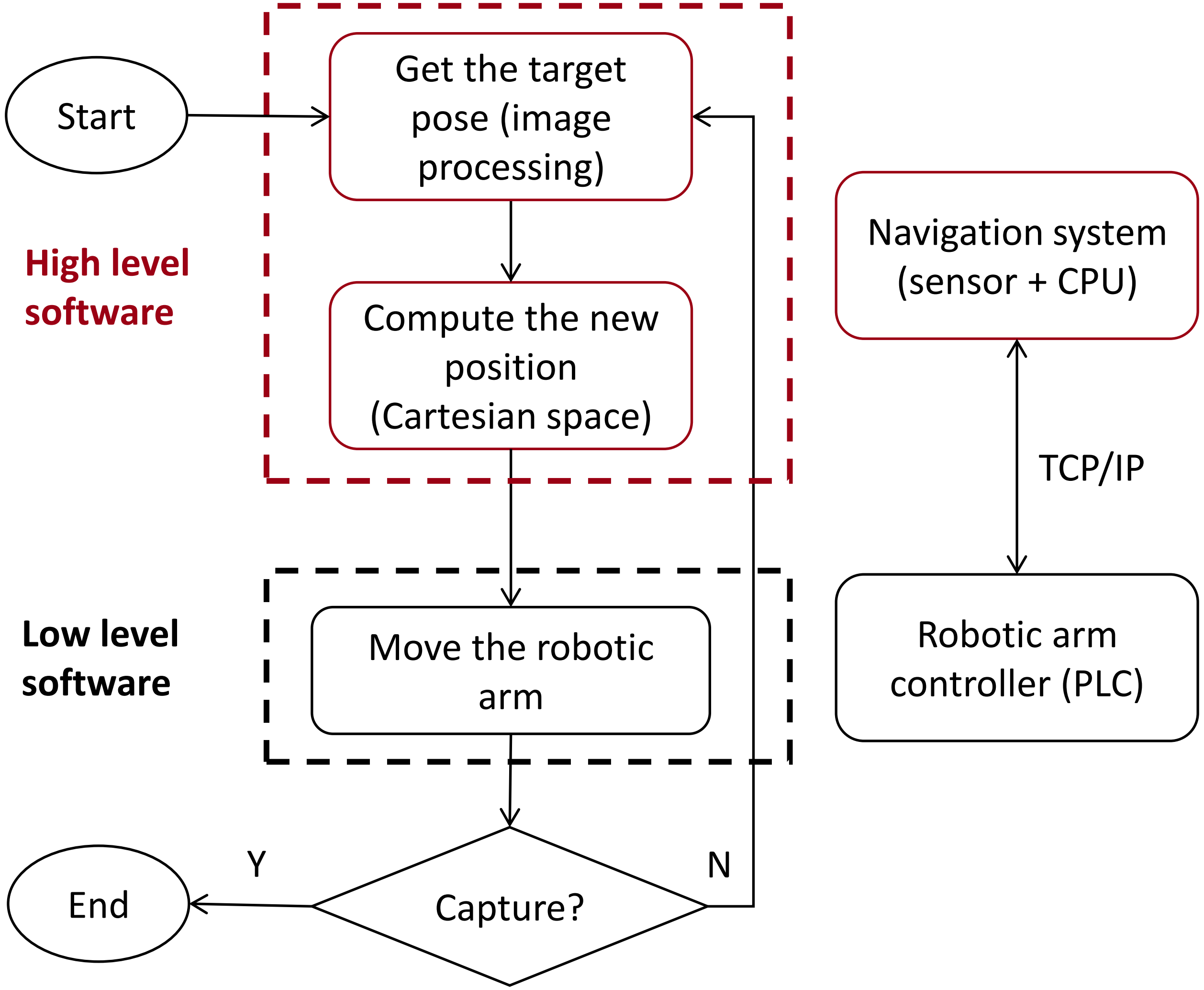
A way to fix the vibrations is to **tune the motors controllers**. To this aim, a trial and error method was followed until a smoother motion was reached (test data evaluation in progress…).

4. Kinematic simulation: close navigation experiment

Kinematic simulation reconstructs the final approach of the **instrumented** end-effector to the target satellite.

The experiment:
- The robotic arm starts from different configurations.
- The target is placed in random place w/ random attitude.
- The navigation sensor places the end-effector in front of the target.





5. Capture interface: first design

Capture interface design came from the experience gained from the previous tests. A gripper type capture interface was chosen.

This choice was driven by different factors:

1. In the interface, each finger is individually actuated, resulting a more tolerance about misalignments (fig. 1).

2. Interfaces are easily adjustable by acting on some “key points” (fig. 3).

3. The active interface creates an horizontal force on the passive interface that tights the capture (fig. 4).

4. Disc-shaped passive interface: there is space to place other hardware for OOS tasks.

5. Using a relative navigation sensor, the active interface becomes autonomous from the satellite base.

Manufacturing to be started soon.

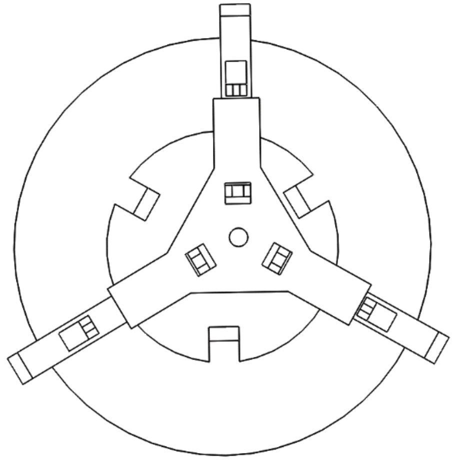


Figure 1

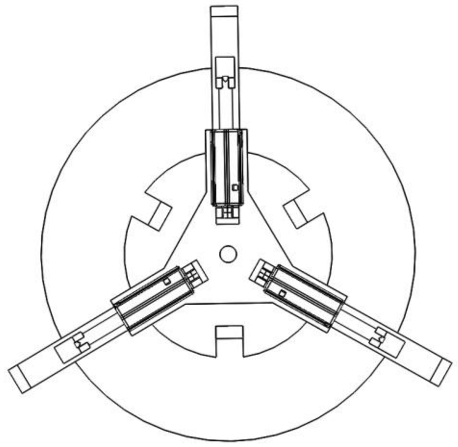


Figure 2

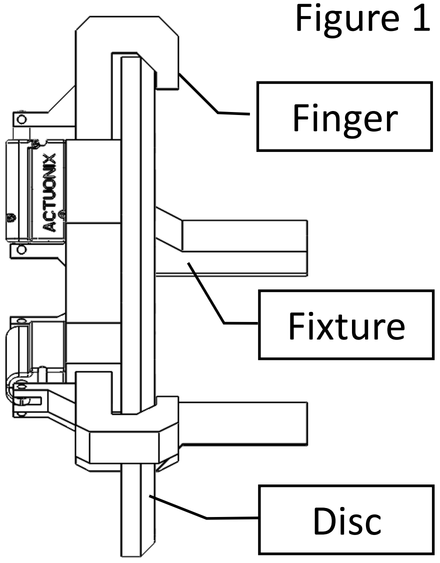


Figure 3

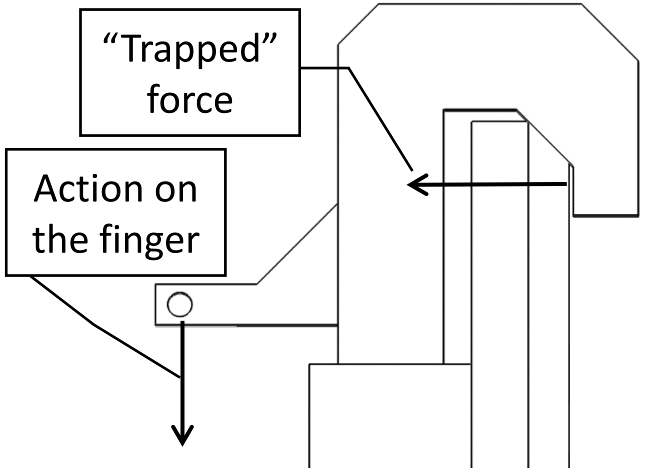
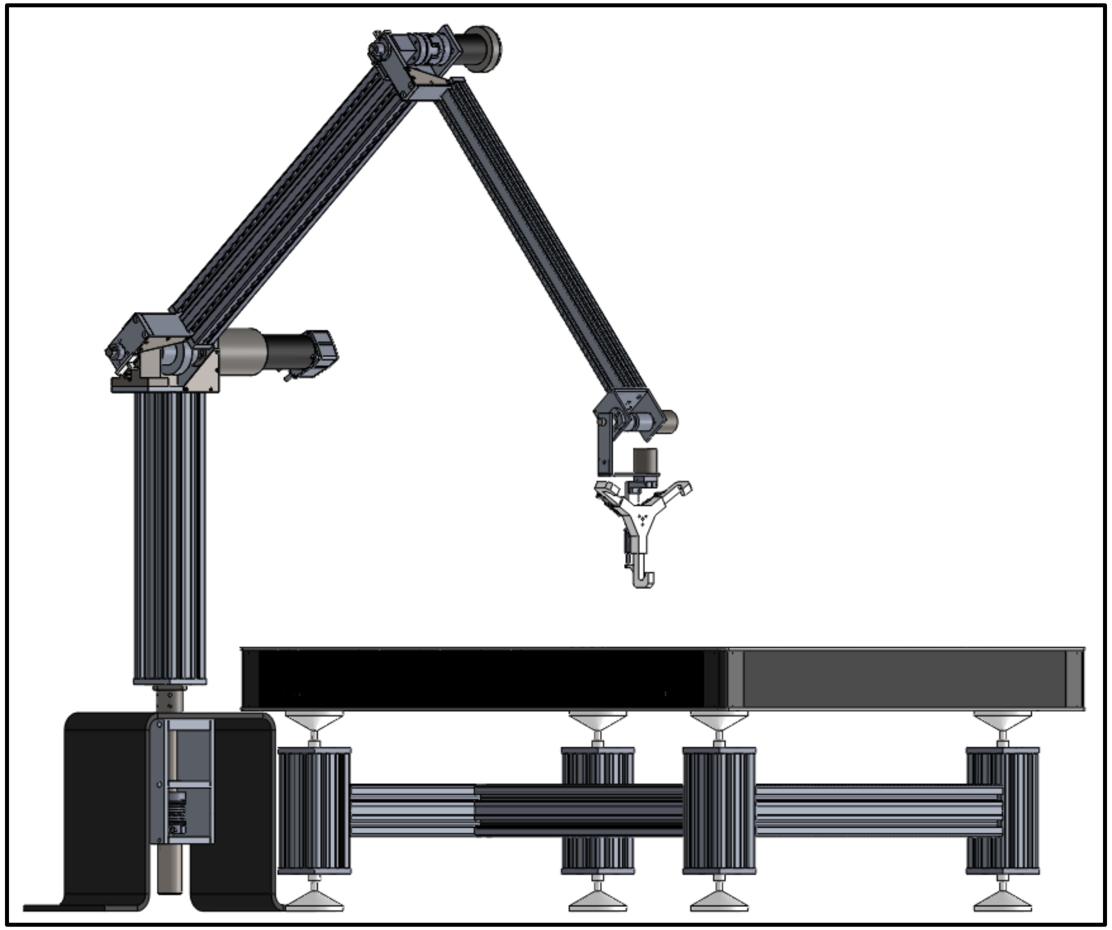


Figure 4

6. Conclusions and future works

Conclusions. In brief, activities performed in the last year:

- ✓ Robot control software.
- ✓ Implementation of the vision sensor.
- ✓ Fix some robotic arm issues (e.g.: vibrations).
- ✓ Test the system Robot & Vision sensor (improve the accuracy).
- ✓ Kinematic simulation.



Future works includes:

1. Improve robotic arm dynamical behavior (upgrade structure).
2. Design and assembly of a low friction table to simulate also the dynamic behavior of the capture with a floating module.
3. Integrate and test the capture interface.

Thank you for your attention

List of publications:

1. Alex Caon, Francesco Feltrin, Francesco Branz, Francesco Sansone and Alessandro Francesconi, ''Ground Facility for Validation of Proximity Operations: a Hardware–In–the–Loop Experiment''. Metrology for Aerospace 2020.
2. Alex Caon, Francesco Branz, Francesco Feltrin, Francesco Sansone, Lorenzo Olivieri, Alessandro Francesconi, ''Integrated tests for relative navigation, docking and capture for small satellites''. *Small Satellite Systems and Services 2020* (postponed to 2021).