POLITECNICO
MILANO 1863

Spacecraft Attitude Dynamics

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Course objectives

The course provides fundamental knowledge of **spacecraft attitude dynamics and control**

(i) Modelling – simulation test-bed
(ii) Undertake attitude stability analysis
(iii) Develop determination algorithms.
(iv) Develop attitude control algorithms.

2 Lectures per week (Thursday and Friday, online)

1 Lab (Wednesday, 2 groups) – bring your laptop with the latest version of **Matlab/Simulink** installed.

Supplementary material: Lecture notes will be added to WeBeep each week.

Attitude definitions

- **Attitude:** orientation of spacecraft body axes relative to a reference frame

- **Attitude error**: difference between true and desired spacecraft attitude

- **Attitude determination**: use of **sensors** to estimate the attitude in real-time

- **Attitude control**: maintain specified attitude with given precision using **actuators**.

Course syllabus

1. Attitude Dynamics and kinematics of spacecraft:

Learning objective - *To be able to* ***model*** *(in Simulink) a spacecraft in the space environment. To understand how to exploit the dynamics of spacecraft for* ***passive stabilization.***

2. Attitude determination:

Learning objective - *To understand and implement attitude determination algorithms using different sensor portfolios.*

3. Ideal attitude Control:

Learning objective – *To develop feedback controls to guarantee control objectives such as (i) de-tumbling (ii) slew motions (iii) three-axis stabilization. To validate these controls.*

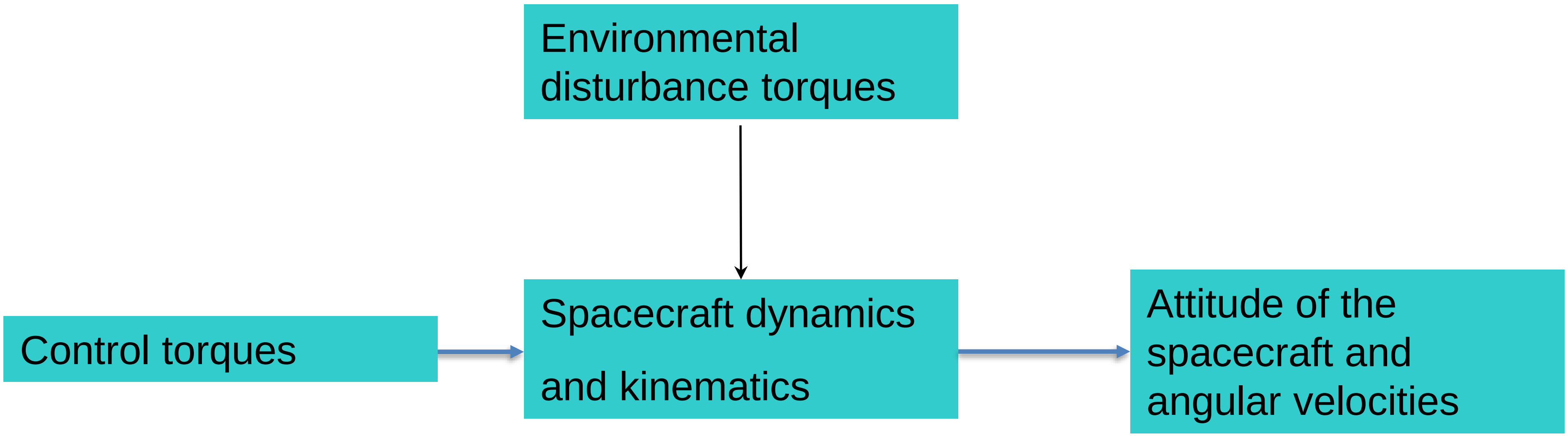
4. Attitude actuators:

Learning objective - *To understand and implement algorithms to generate "ideal" torques using different types of actuators.*

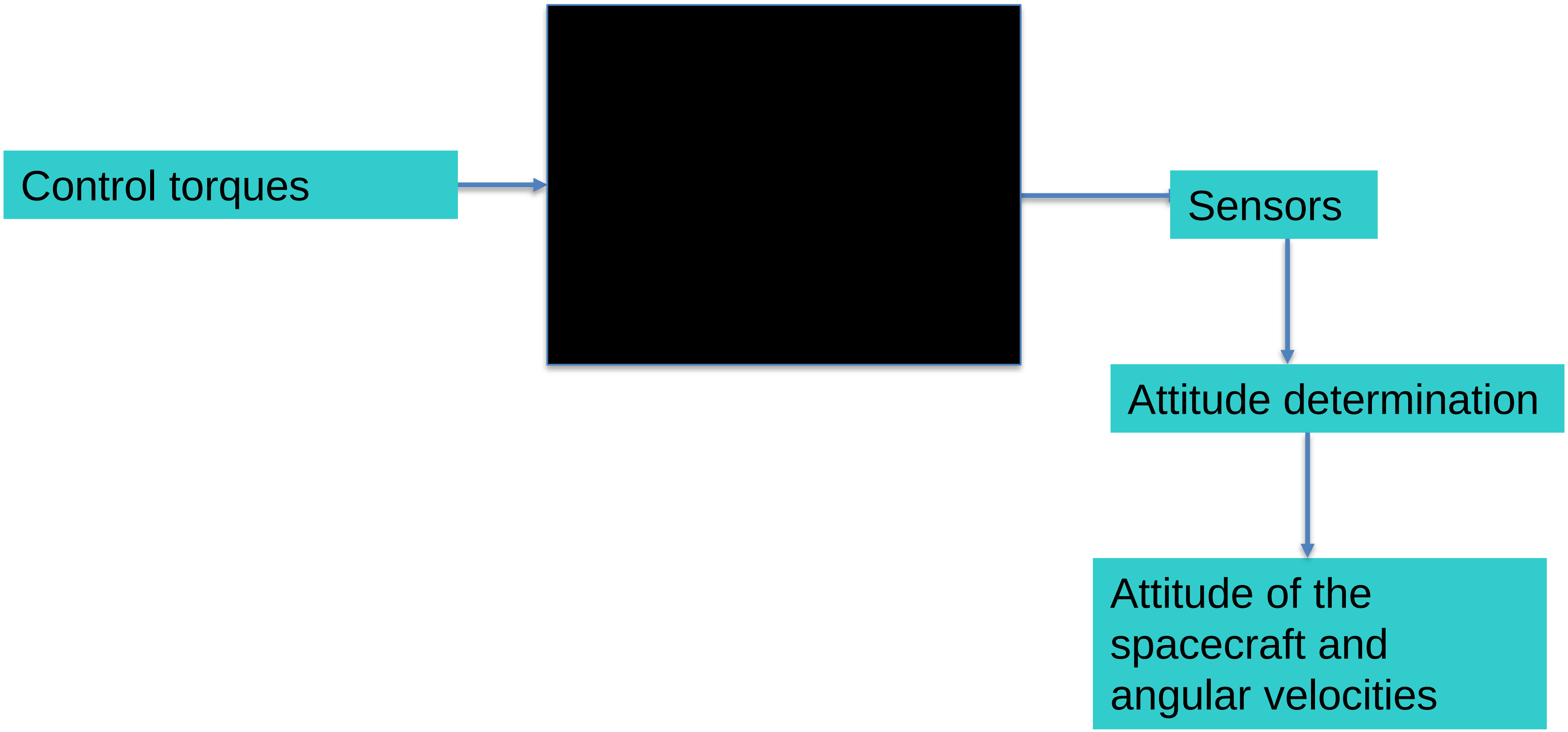
5. State-space approach to control system design:

Learning objective - *To understand and implement algorithms to design optimal state and output feedback controllers.*

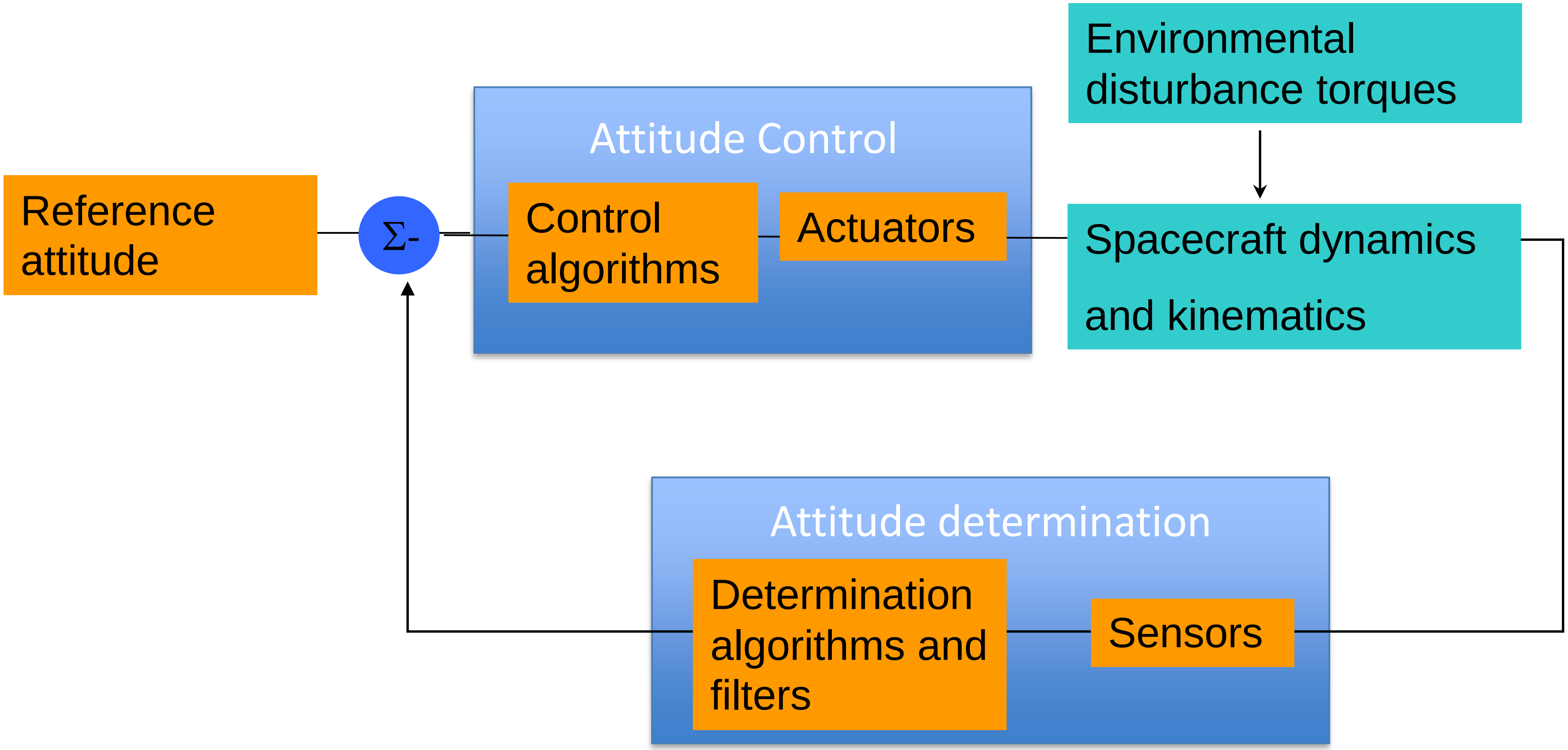
Develop a spacecraft model



Sensors are required to measure the attitude of the spacecraft



Attitude control loop



Attitude control loop

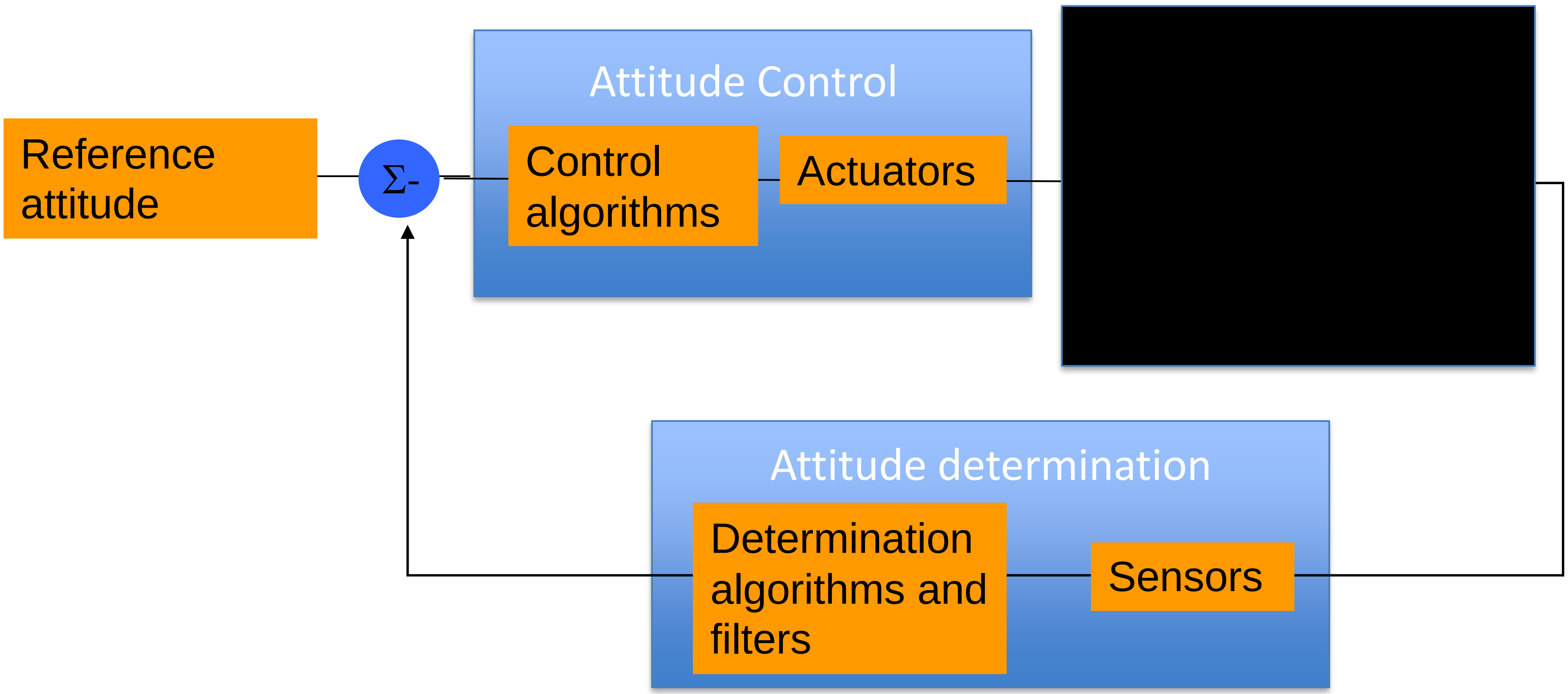
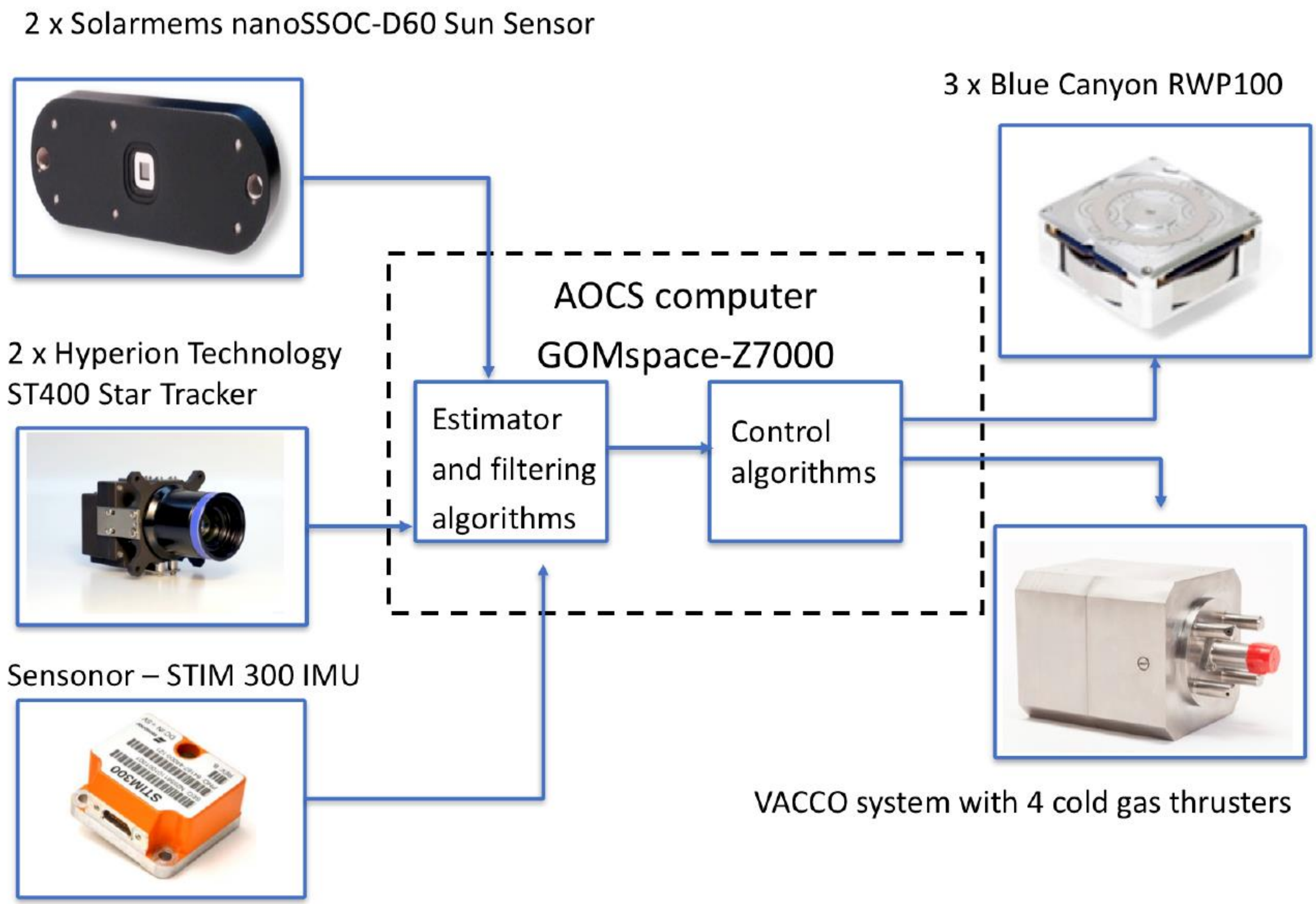


Figure: ADCS Architecture



Suggested textbooks - Theory

Landis Markley, F. Crassidis, J.L.: *Fundamentals of Spacecraft attitude determination and control*, Space Technology Library, Springer, 2014.

J.Wertz: *Spacecraft Attitude Determination and Control*, D.Reidel Publishing Company.

Friedland, B.: *Control System Design: An Introduction To State-Space Methods*, McGraw-Hill

M.J. Sidi: *Spacecraft dynamics and control: a practical engineering approach*, Cambridge University Press.

Wie, B.: *Space Vehicle Dynamics and Control*, Editor: AIAA Education Series

Shaub., H., Junkins., J.: *Analytical Mechanics of space systems* 2nd Edition AIAA, 2009.

Additional course notes – WeBeep channel

Lecture notes, prof. Bernelli

Selected lecture notes on control theory, prof. Dozio.

Lecture slides.

Useful websites for CubeSat ADCS

https://gomspace.com/shop/subsystems/attitude-orbit-control-systems/default.aspx

https://hyperiontechnologies.nl/products/

https://www.cubesat-propulsion.com/

https://www.bluecanyontech.com/components

https://honeybeerobotics.com/portfolio/microsat-control-moment-gyroscopes/

https://www.cubesatshop.com/

https://www.sensonor.com/

Pre-requisites

Elementary knowledge of orbit theory.

Basic knowledge of system dynamics.

Basic knowledge of system theory.

Basic knowledge of single-input-single-output classical control (frequency domain).

Examination

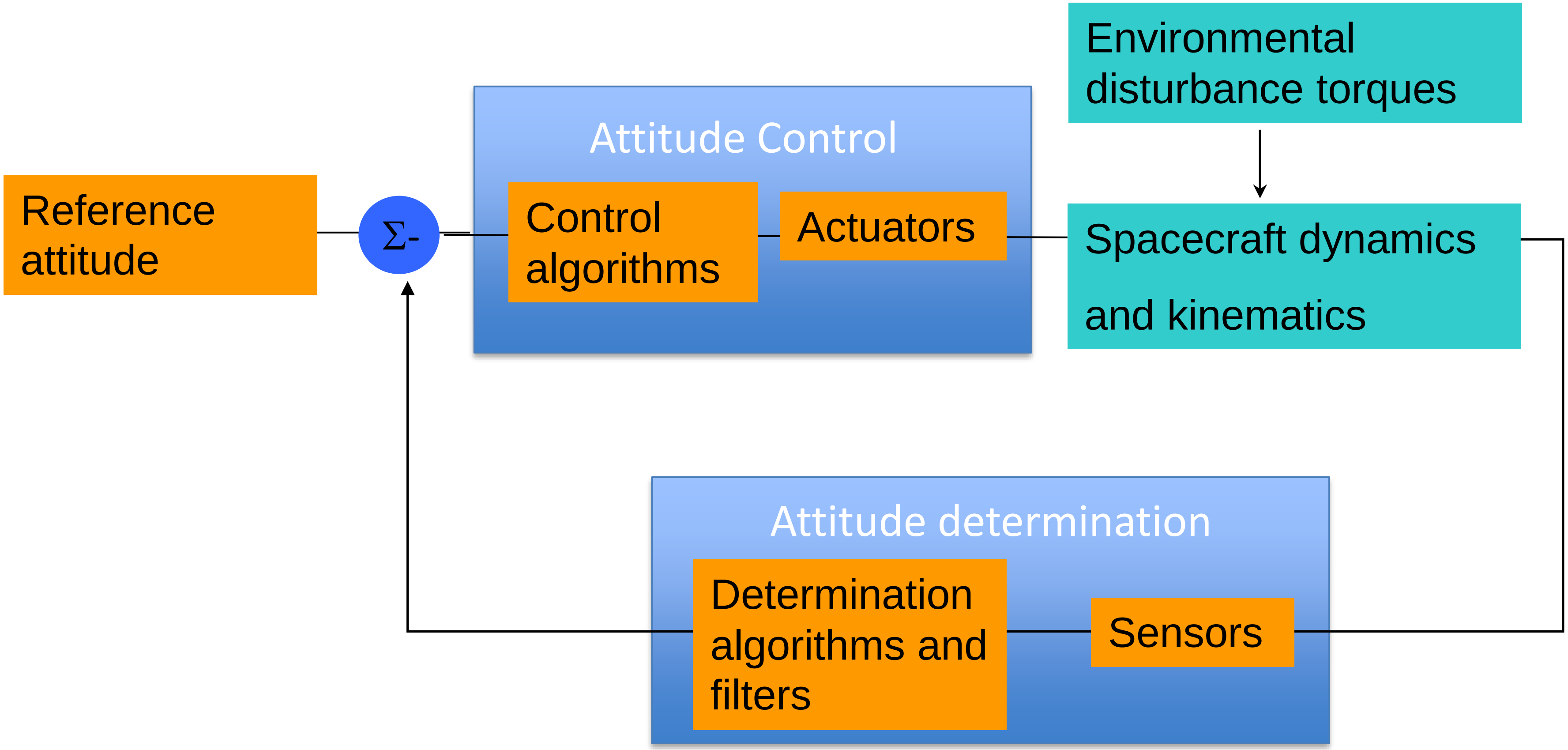
Project: max. 20-page report. **Note you should also submit your Simulink files.**

Oral examination on all aspects of the course

Report delivery via the delivery folder on WeBeep, **deadline January 7** regardless of date of oral exams.

Objectives of projects

- Simulate the complete attitude dynamics and control loop



- Show and quantify that the attitude control improves the pointing performances with respect to the uncontrolled case. Define at least 1 performance parameter and make statistical analysis on it.

Groups for projects

The project will be carried out in **groups**, with the following rules:

- Each group should have **4 members.**
- To promote diversity, each group **must** include at least one student who did not study the bachelor's degree at PoliMi.
- **The groups will be registered through a form that will be available online.** Do not submit group information by hand or email.
- The groups could be the same for the course of Orbital Mechanics.

Also, please consider the following recommendations:

- **Completing the project is a prerequisite to sit for the oral exam**. If you do not intend to do the project/exam now, avoid teaming up with people that do.
- **This is a team effort**. You can distribute the tasks, but everybody is responsible for the final result. At the oral exam, **any member can be questioned about any part of the work**.

Project specifications

- Orbit specifications NOT assigned (you can use the orbit of your Orbital Mechanics assignment)
- Class of spacecraft assigned, either cubesat (3U, 6U, 12U - mass 4 to 15 kg), microsat (10 to 100 kg), minisat (100 to 500 kg), large satellite (over 500 kg)
- Pointing requirements NOT specified, you should define them (justify selection)
- You are expected to model the attitude dynamics including 2 perturbing torques, selecting the most relevant for your orbit and spacecraft shape (justify selection)
- Attitude parameters assigned, you are expected to use those to simulate attitude kinematics
- One sensor assigned, you are expected to use this and eventually add any other sensor, if needed (justify choice)
- Actuators assigned, you are expected to use those and eventually add any other actuator, if needed (justify choice)
- Control logic NOT assigned, choose one and implement it
- Specifications can be modified **only if strictly necessary**
- Simulate at least one full orbit

Project specifications

Mission: (i) de-tumble (ii) slew maneuver (iii) Earth/Sun/inertial pointing with 3 axis stabilization

Each group member responsible for performances in one of: (i) attitude determination (ii) de-tumble (iii) slew maneuver (iv) pointing with 3 axis stabilization

Specifications can be modified **only if strictly necessary**

Report Structure

- **Length –** maximum 20 pages (excl. cover and index), minimum font size 11, single column
- **Figure** – Block scheme of the ADCS architecture (e.g. sensors + actuators + controller + algorithms + kinematics)
- **Model description –** models used and assumptions
- **Control and determination algorithms –** <u>justify choices</u>
- **Results** – Clear plots with axes labels and units, <u>compare and contrast algorithms</u>
- **References -** all material used, including theoretical and data of the hardware

<u>Define notation used, do not copy and paste Simulink diagrams or plots.</u>

Report Delivery

- Report delivery via the delivery folder on WeBeep
- Deadline for delivery is January 7, regardless of date of oral exam (delivery folder will be closed after that date)
- Deliver project report in pdf format and Simulink code in a separate zip file
- PLEASE use these names for the files you upload:
    - GroupNN.pdf (example Group01.pdf) for the project report
    - GroupNN.zip (example Group01.zip) for the Simulink files

Labs – Modelling and algorithm development in Simulink

Lab 1: Introduction to Matlab/Simulink (simple models).

Lab 2: Introduction to Matlab/Simulink (more complex models).

Lab 3: Simple and dual-spin rotational dynamics.

Lab 4: Attitude kinematics equations.

Lab 5: Attitude kinematics equations.

Lab 6: Gravity gradient disturbance.

Lab 7: Solar radiation and magnetic torque.

Lab 8: Models of sensors and attitude determination.

Lab 9: Models of actuators.

Lab 10: Implementation of control logic.

Lab 11 and 12: Group project development.

Schedule

1. Wednesday – 10:15-13:15, lab L13 (initially, students with odd person code) + online

2. Wednesday – 14:15-17:15, lab LM1 (initially, students with even person code) + online

3. Thursday – 8:15-10:15, online lecture

4. Friday – 14:15-17:15, online lecture

When online, please do not use chat to ask questions, use microphone and speak.

Teaching assistants

Andrea Colagrossi

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Antonio Rizza

Notices

1. Bring in your laptop for the lab sessions

2. Install Matlab Simulink