SPACECRAFT DYNAMICS

ATTITUDE : orientation of spacecraft body axes relative to a reference frame → we will use absolute attitude relative to a inertial frame and relative attitude relative to a orbit frame of reference that is not inertial.

ATTITUDE ERROR : difference between true and desired spacecraft attitude

ATTITUDE DETERMINATION : use of sensor to estimate the attitude in real-time.

ATTITUDE CONTROL :

Spacecraft Attitude Dynamics and Control
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

1 Lab – bring your laptop with the latest version of **Matlab/Simulink** installed.

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

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 Beep, 1 week before the exam and code in a zip file.

Project specifications:

- orbit specifications NOT assigned (can combine with Orbital Mechanics assignment)
- part of the attitude specifications assigned

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.***

↳ It will include the analisys of the stability of a s/c

2. Attitude determination

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

3. Ideal attitude Control:

After deploy from the launch sistem the spacecraft need to stop rotating + deploy solar panel → align with a certain direction

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.*

↳ reduce angular velocity bellow a certain values → stop angular rotation.

→ in some project it is necessary to develop algorithm to control the s/c.

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 (10 Credits course only):

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

Develop a spacecraft model

second order effect → we will consider them later in the course

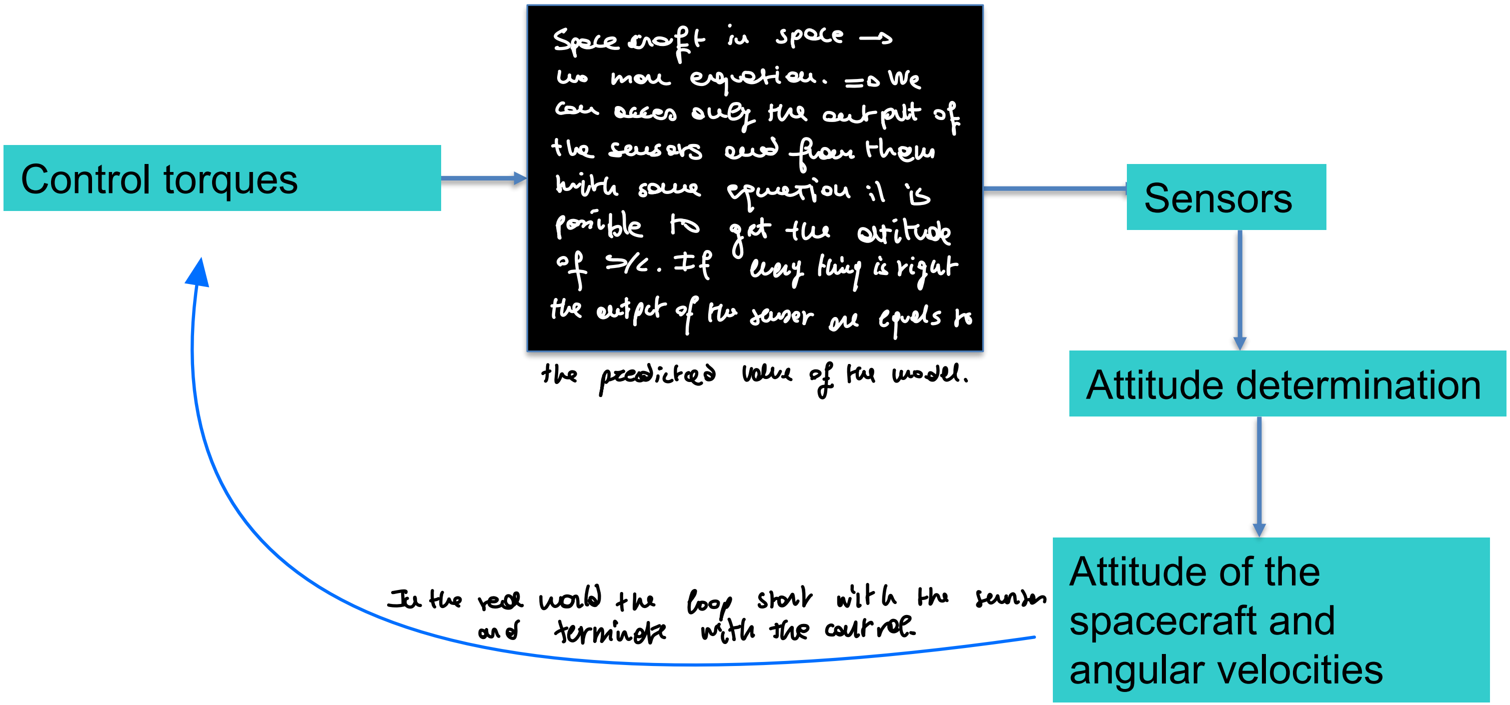
Environmental disturbance torques

→ can depend on the position of the spacecraft in space:
- orientation of the spacecraft forces and torque
- orbital dynamics → position in the orbit.

Control torques → Spacecraft dynamics and kinematics → Attitude of the spacecraft and angular velocities

numerical simulation and integration.

Sensors are required to measure the attitude of the spacecraft

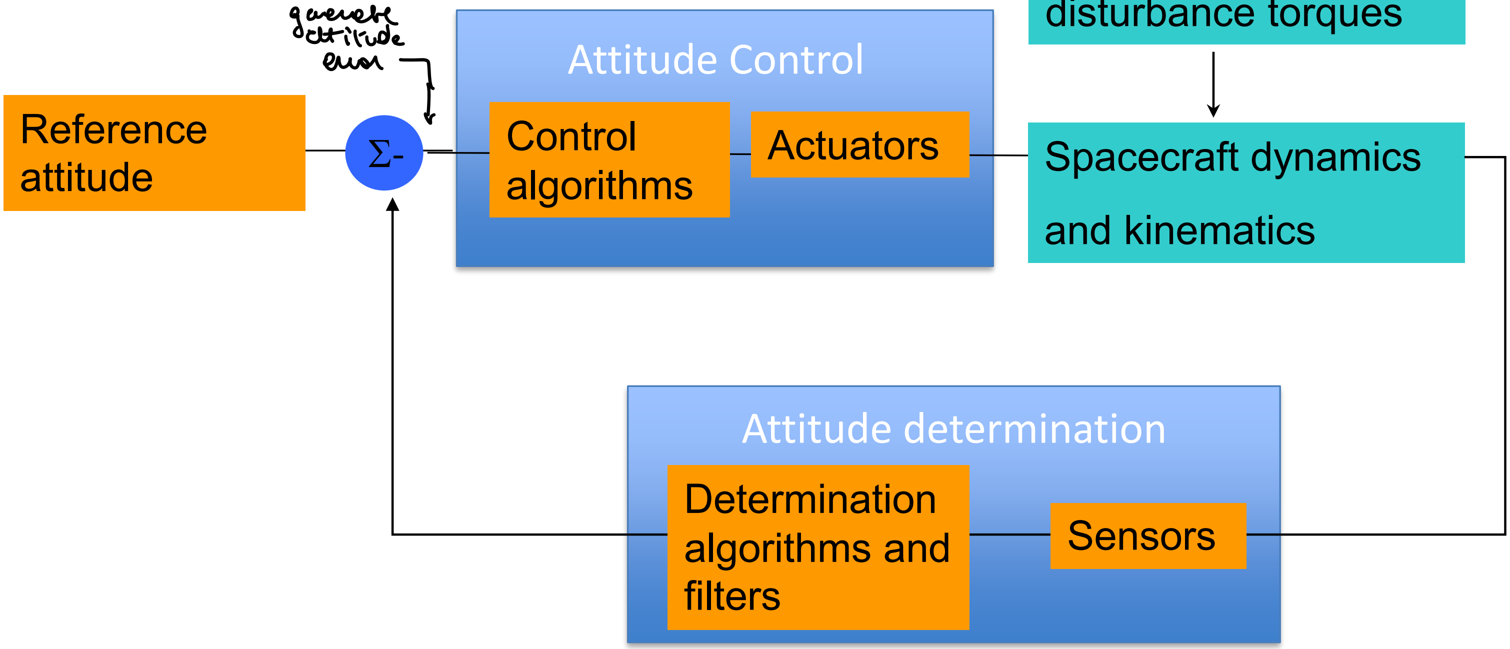


Attitude control loop

These two boxes substitute the real object.

input to the Attitude control.

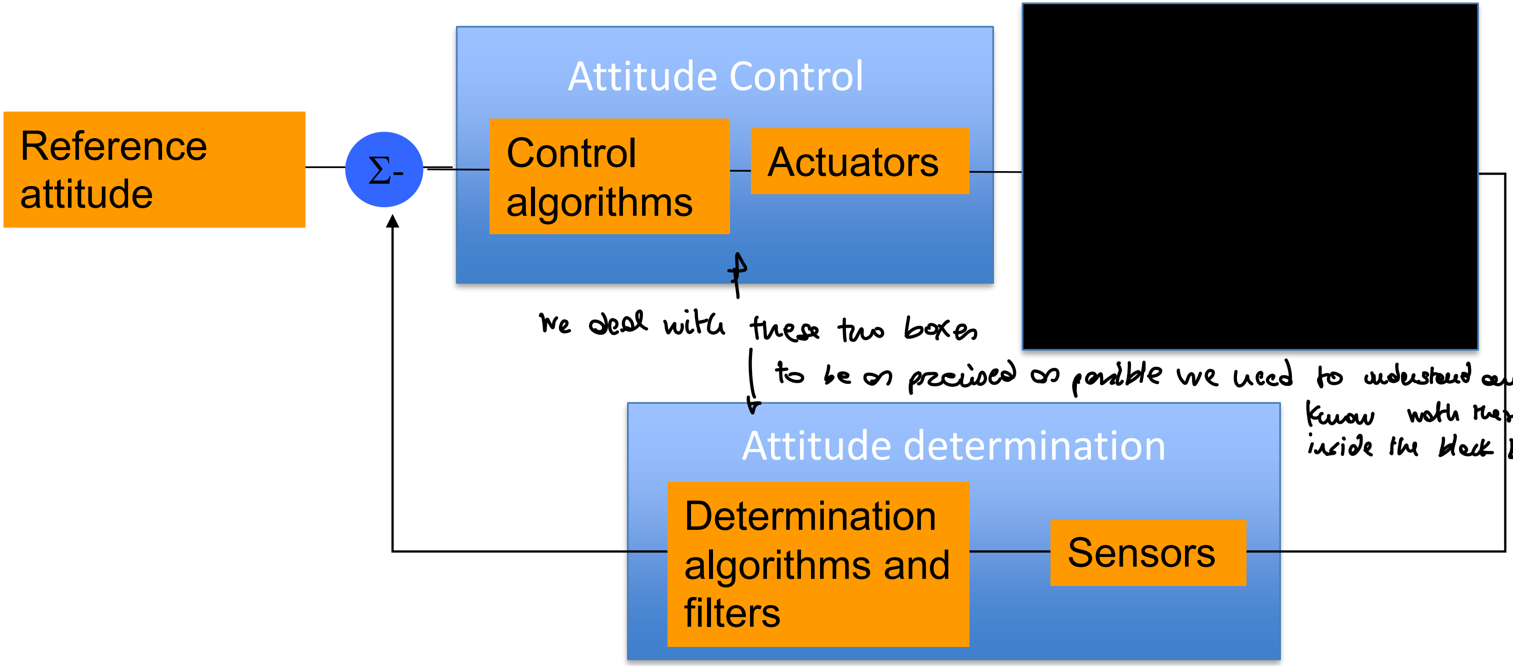
generate attitude error



real object given in formation to the sensors

Attitude control loop

↳ Real Application.



we deal with these two boxes

to be as precise as possible we need to understand and know what there is inside the black box.

Suggested textbooks - Theory

J.Wertz: *Spacecraft Attitude Determination and Control*, D.Reidel Publishing Company. 350 € (Amazon) — 181 € (ebook)

Landis Markley, F. Crassidis, J.L.: *Fundamentals of Spacecraft attitude determination and control*, Space Technology Library, Springer, 2014. → 65 €

Shaub., H., Junkins., J.: *Analytical Mechanics of space systems* 2nd Edition AIAA, 2009. → 104 €

M.J. Sidi: *Spacecraft dynamics and control: a practical engineering approach*, Cambridge University Press. → 68 € ⟸ Molto interessante

Wie, B.: *Space Vehicle Dynamics and Control*, Editor: AIAA Education Series → 35 €

Friedland, B.: *Control System Design: An Introduction To State-Space Methods*, McGraw-Hill → 25 € (pdf).

Additional course notes – Beep channel

Lecture notes, prof. Bernelli

Lecture notes, prof. Biggs

Selected lecture notes on control theory, prof. Dozio.

Lecture slides.

Attitude control of nano-spacecraft project

Lo Cube sat

Type: 3U, 6U, 12U, 16U

Depends on the vision

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

first thing to do

Orbit: LEO of varying altitudes and inclinations

Hardware:

position of star to determine the position and orientation of the s/c

Sensors: gyro, magnetometer, star sensor, Sun sensor, Earth horizon sensor

Actuators: Control Moment Gyros, Reaction wheels, electric thrusters or cold gas thrusters, magnetic torquers

work on gyroscopic effect.

common to all the spacecraft orbiting in a LEO

The size of the s/c drives the size of the actuators where the smaller the better either if we have a nano s/c or the ISS.

Report Structure – 20 pages, minimum font size 12, single column.

→ No structure will be provided → feel free to use whatever we like

- **Figure -** ADCS architecture → overall architecture of the model
- **Model description –** models used and assumptions
- **Control and determination algorithms –** justify choices
  No just copy and paste from lecture.
- **Results** – Clear plots with axes labels and units, compare and contrast algorithms → critical evaluation of the results.
- **References -** all material used, including theoretical and data of the hardware

Define notation used, do not copy and paste Simulink diagrams or plots.

→ Do not use aerospace blockset in simulink → We should develop our own block unless they are fully understood by me

Useful websites for CubeSat ADCS

there won't be a space craft dimension specification → Develop a useful model for a spacecraft and it is important to understand what kind of spacecraf we will work with. It is important to understand the typical performance of the sensor used. ⇒ It is easier to find specification for Cubesat because they are made up by standard part.

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/

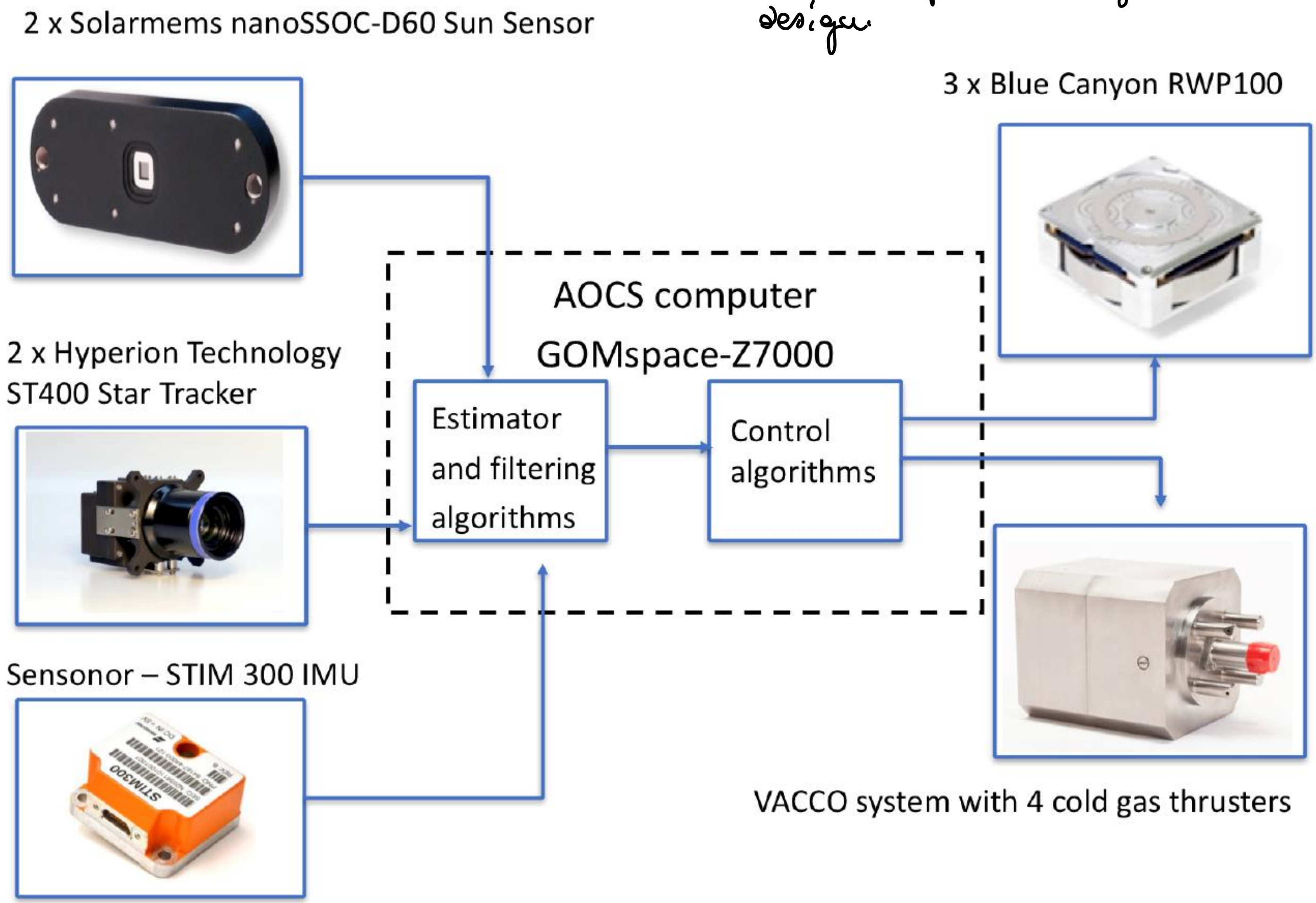
https://www.cubesatshop.com/

https://www.sensonor.com/

Figure: ADCS Architecture

→ Example of an Architecture of the space craft.

NOTE some kind of redundancy are baked in the design.



Labs – Modelling and algorithm development in Simulink

Lab 1: Analysis of the Euler equations.

Lab 2: Analysis of passively controlled spacecraft.

Lab 3: Attitude kinematic equations.

Lab 4: Gravity gradient disturbance.

Lab 5: Static Attitude determination.

Lab 6: Filtering and dynamic attitude determination.

Lab 7: Ideal controls.

Lab 8: Control with momentum exchange devices.

Lab 9: Magnetic attitude control.

Lab 10: Control with thrusters.

Schedule

1. Wednesday – 11:15-13:15, online lecture (ALL)
2. Wednesday – 13:15-14:15, online lecture on control theory (10 Credit course)
3. Friday – 13:15-15:15, online lecture (ALL)
4. Thursday – 17:15-20:15, labs.
   L06 (8 Credit course) + online
   L02 (10 Credit course) + online

Teaching assistants

8 Credits course

Andrea Colagrossi

10 Credits course

Marco Nugnes

Giovanni Zanotti

Notices

1. Bring in your laptop for the lab sessions

2. Install Matlab Simulink