

Literature for ADCS design



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Made by Group 827

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# Books & Theory

This folder contains the books and papers useful for ADCS design.

## Fundamentals of Spacecraft Attitude Determination and Control

Author: F.Landis Markley, John L. Crassidis

ISBN: 978-1-4939-0801-1

Short summary:

Good entry level book for understanding both estimation and control of satellite attitude.

Recommended chapters:

* Chapter 2: Most parametrizations of attitude. Place attention in quaternions specifically.
* Chapter 3: Kinematic equations of parametrizations and introduction to dynamics of rotating frames and free body attitude dynamics.
* Chapter 5: Attitude estimation
* Chapter 7: Attitude control

## Quaternion feedback regulator for spacecraft eigenaxis rotation

This paper contains a guide for quaternion attitude control with gyroscopic precession correction. It focuses on control efforts that rotate around the eigenaxis, that is, the minimum rotation required.

## Spacecraft Attitude Determination and Control

Author: James R. Wertz

ISBN: 9027709599, 9027712042

Short summary:

Good entry level book for understanding both estimation and control of satellite attitude.

Recommended chapters:

* Chapter 12: Parametrizations of attitude
* Chapter 15&16: Rotational dynamics of a free body.
* Chapter 17: Attitude determination
* Chapters 18&19: Attitude stabilization and control

## MEKF & Quaternions

This folder includes extra material for attitude determination employing a Multiplicative Extended Kalman Filter(MEKF), as well as more information about quaternions.

It includes:

* Holy Grail of quaternions: In depth paper about quaternions and manifold theory.
* MEKF – First Paper: First paper about MEKF from its inventor.
* MEKF – In depth: More thorough explanation of the math behind the MEKF, and the second order MEKF.
* MEKF – Implementation: Example of MEKF used in practice.

# NASA material for CubeSat development

This folder includes documentation from NASA related to CubeSat design.

## ADCS design guide

Short paper that explains the recommended methodology for ADCS requirements definition, component selection and common disturbances. Really useful to take a quick read to understand the process in general

## CubeSats 101 - Basic Concepts and Processes for First-Time CubeSat Developers

Entry level handbook containing all pertaining information about the whole CubeSat process. It is useful to check for questions about this type of satellite.

## CubeSat papers

Link to the NASA repository of new advancements related to CubeSat technology.

## CubeSat Design Specification Rev14

This file contains the official design specifications for CubeSat satellites.

## CubeSat.url

Official webpage for the CubeSat specifications and conferences. American university.

# MIT Courses

-[Satellite engineering](https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/pages/syllabus/): General course about satellites

-[Space Systems engineering](https://ocw.mit.edu/courses/16-83x-space-systems-engineering-spring-2002-spring-2003/pages/lecture-notes/): Random satellite stuff

-[Aerospace dynamics](https://ocw.mit.edu/courses/16-61-aerospace-dynamics-spring-2003/pages/lecture-notes/): Seems really useful

-[Space System Architecture Design](https://ocw.mit.edu/courses/16-892j-space-system-architecture-and-design-fall-2004/): Satellite architectures

-[The Aerospace Industry](https://ocw.mit.edu/courses/16-812-the-aerospace-industry-spring-2004/pages/lecture-notes/): Seems like a really good summary of satellite history

-[Estimation and Control of Aerospace Systems](https://ocw.mit.edu/courses/16-30-estimation-and-control-of-aerospace-systems-spring-2004/): Controller design and implementation

- [Engineering Apollo: The Moon Project As A Complex System](https://ocw.mit.edu/courses/sts-471j-engineering-apollo-the-moon-project-as-a-complex-system-spring-2007/): Story of the Apollo and how it was designed.

-[Space propulsion](https://ocw.mit.edu/courses/16-522-space-propulsion-spring-2015/pages/lecture-notes/): Math and alternate methods.

# Satellites

This folder contains the different AAU projects in ADCS. Each project is represented by the following template.

**Title:** Example project name **Year:**2019

Satellite information

**Satellite:** AAUSAT6

Problem to solve

**Problem Statement:** “How to stabilize the satellite with flywheels w.r.t. 3D rotations given its attitude.”

**Subsystem to design:** Attitude Control System in pointing mode

Solution definition

**Sensors & Actuators:** Flywheels

**Parametrization method:** Quaternions

**Algorithms employed:** State space, PI controller + minimum energy control

Project conclusion

**Results:** Simulations ok, requirements met, implementation failure with “x”, failed requirement “TRy” because of “z”

**Shortcomings:** The flywheels saturate over time, rendering the controller unusable. The minimum-energy method is computationally expensive. Code must be rewritten.

**Possible Improvements:** Add magnetorquers for desaturation.

**Extra interesting notes:** Quaternions employed for control.

### **Title:** Attitude Control System for AAUSAT6 **Year:** 2018

Satellite information

**Satellite:** AAUSAT6

Problem to solve

**Problem Statement:**

“*How can a control algorithm be developed that enables a CubeSat to obtain the pointing precision required for a camera payload?*

*− How can this be done through full 3-axes attitude control with basis in the available testbed using reaction wheels for actuation?”*

**Subsystem to design:** ACS

Solution definition

A diagram of a block diagram

Description automatically generated**Sensors & Actuators:** Reaction wheels

**Parametrization method:** Quaternions

**Algorithms employed:** state-space study of system with linearization around working conditions. Controllers are designed with classical methods as PI controllers. Precompensation of Coriolis effect for RHP removal and plant simplification.

Project conclusion

**Results:** Simulations work. Nadir pointing error of 1.241º after 175s → satisfactory

Point tracking error of 0.3º max → satisfactory

Type 2 disturbance rejection system.

**Shortcomings:** Acceptance testing not possible because of saturation. No state space controlling employed. Simulations yielded no saturation, contrary to belief and the real system

**Extra interesting notes:** A study was conducted for the desired motion of the satellite in tracking mode, as well as a thorough investigation of the speed bias required for the operation and its power consumption.

### **Title:** CubeSat ADCS **Year:** 2023

Satellite information

**Satellite:** AAUSAT6.

Problem to solve

**Problem Statement:** N/A (chapter 3 mentions purpose of designing an ACDS with focus on ACS, assuming ideal ADS).

**Subsystem to design:** Linear state space model (LQR for feedback), control block for reaction wheels

Solution definition

**Sensors & Actuators:** Magnetorquers, Thrusters, Reaction wheels.

**Parametrization method: Euler Angles,** Quaternions.

**Algorithms employed:** Linear state space model (uses LQR), Classical controlling (cascade).

Project conclusion

**Results:** Simulation results – all passed.

**Shortcomings:** No physical testing,

**Possible Improvements:** Steady state error management, momentum dumping via magnetorquers.

**Extra interesting notes:** 6th semester

### **Title:** CubeSat Sliding Mode Attitude Control **Year:** 2016

Satellite information

**Satellite:** AAUSAT6

Problem to solve

**Problem Statement:** “Develop an attitude control system for a CubeSat. The attitude control system must be capable of: Nadir pointing, Active pointing, rejecting orbit disturbances.”

**Subsystem to design:** ADS and ACS (pointing tracking mode)

Solution definition

**Sensors & Actuators:** Flywheels

**Parametrization method:** quaternions

**Algorithms employed:**

* ACS State Space and active filtering LQR for omptimal control calculation. Also uses sliding mode control
* ACS: MEKF for quaternion, model rotational speed and flywheels rotational speed.

Project conclusion

**Results:** Linear controller: 5sec for 75 deg compensation

Sliding mode controller: 4sec for 75 deg. compensation

**Shortcomings:** Estimator poses an error of >5 deg, and behaves erratically with >90 deg steps.

**Possible Improvements:** Coriolis force compensation. Alternative estimation methods for large errors.

**Extra interesting notes:**

The proposed modes include:

* Orbit insertion: By CubeSat restrictions, no actuation for 45 mins
* Contingency: Usable in case of danger, only mechanical.

It is mentioned AAUSATS 1 to 4 use magnetorquers only.

### **Title:** Attitude Determination and Control System for AAUSAT **Year:** 2014

Satellite information

**Satellite:** AAUSAT5

Problem to solve

**Problem Statement:** N/A

**Subsystem to design:** ADS and ACS

Solution definition

**Sensors & Actuators:** (here they employ the AAUSAT 4 configuration as a baseline) 6 sun sensor(2 photodiodes each, one sun sensor per side), 2 gyroscopes, and 2 magnetometers. 3 magnetorquers

**Parametrization method:** Matrices for reference changes, quaternions for control

**Algorithms employed:**

* Determination: Whaba’s theorem for finding the rotation matrix.
* Control: Classical lead controller for 1 axis stabilization

Project conclusion

**Results:** Did not work.

**Shortcomings:** 1 axis actuation does not consider the coupling between axis.

**Possible Improvements:** Scrap it and do better modelling

**Extra interesting notes:** Contains a study of the transformation between common reference frames.

There exists a simulation environment for satellites created for AAUSAT3

Contains a diagram of AAUSAT4 ADCS

### **Title:** Testbed for CubeSat with ADCS based on magnetorquers[[1]](#footnote-2) **Year:** 2014

Satellite information

**Satellite: AAUSAT5**

Problem to solve

**Problem Statement:** ***How is it possible to construct a testbed for CubeSats, that can test ADC-systems based on magnetorquers?***

**Subsystem to design:** ADCS, testbed (helmholtz cage), satellite trap[[2]](#footnote-3)

Solution definition

**Sensors & Actuators:** Magnetorquers, coils (used in Helmholtz cage).

**Parametrization method:** none

**Algorithms employed:** ??? (The project focused on Analogue Circuit Design)

Project conclusion

**Results:** partial success.

**Shortcomings:** precision of prototype testbed,

**Possible Improvements:** Report writing I guess

**Extra interesting notes:** 2. Semester project.

### **Title:** Attitude Determination and Pointing Control System for AAUSAT4 **Year:** 2013

Satellite information

**Satellite:** AAUSAT4

Problem to solve

**Problem Statement:** N/A

**Subsystem to design:** ACDS split into ADCS1 responsible for detumbling the satellite and ADCS2 for pointing purposes. An ACS.

Solution definition

**Sensors & Actuators:** Magnetometer, magnetorquers, sun sensor (photodiode), gyroscope

**Parametrization method:** Quaternions

**Algorithms employed:**

* Determination: Whaba’s theorem using SVD for finding the rotation matrix.
* Control: PD-controller

Project conclusion

**Results:** Some success: Simulations showed positive results, but in real-world testing, attitude estimation failed due to sun sensor errors. Challenges in achieving nadir pointing and unperformable acceptance test without a PWM driver. ADS acceptance test successful, and ACS testing missing due to no PWM driver.

**Shortcomings:** Magnetorquers limit arbitrary attitudes.

**Possible Improvements:**

* Explore advanced attitude determination, consider Kalman Filtering for accuracy in eclipse.
* Desire for non-linear controller, needing advanced knowledge.

**Extra interesting notes:** 6. Semester project.

### **Title:** Image-Based Navigation in Space **Year:** 2014

Satellite information

**Satellite:** AAUSAT5

Problem to solve

**Problem Statement:** N/A

**Subsystem to design:** Attitude estimation with earth tracker.

Solution definition

**Sensors & Actuators:** -

**Parametrization method:**

**Algorithms employed:** Picture comparison with simulated data and information sent to ground station: no real-time attitude determination. The processing method is “template-matching”

Project conclusion

**Results:** Algorithm dies work, compression and decompressions methods have been designed.

**Shortcomings:** Circular project, simulated instead of real images

**Possible Improvements:**  Usage of real pictures, inclusion of atmospheric processes, like clouds.

**Extra interesting notes:** Explains the purpose of all AAUSATs

### **Title:** Attitude control system for AAUSAT4 **Year:** 2014

Satellite information

**Satellite:** AAUSAT4

Problem to solve

**Problem Statement:** N/A (Chapter 1: summary, mentions about focussing on ACS)

**Subsystem to design:** ACS, ADS, Controller

Solution definition

**Sensors & Actuators:** Magnetometer, gyroscope, temp. senso, photodiodes, Magnetorquers.

**Parametrization method:** quarternions, rotational matrices.

**Algorithms employed:** Kalman filtering.

Project conclusion

**Results:** Fine simulation results, acceptable test results (all requirements passed, comments based on the system).

**Shortcomings:** Magnetorquer control (varying with orbit around earth because of change in earth’s magnetic field)

**Possible Improvements:** Linearization in all axes instead of 1 axis (created problems for rotation control with magnetorquers in more than one 1 axis), Utilize torque wheels for rotation and magnetorquers for momentum dumping,

**Extra interesting notes:**

### **Title:** Attitude determination and control system for AAUSAT3 **Year:** 2010

Satellite information

**Satellite:** AAUSAT3

Problem to solve

**Problem Statement:** N/A (chapter 1.4 talks about motivation for producing ADCS)

**Subsystem to design:** ADCS, permanent magnets, magnetorquers, Control system for detumbling, Controller for attitude stabilization

Solution definition

**Sensors & Actuators:** Magnetometer, sun sensor, gyroscope, permanent magnets, magnetorquers.

**Parametrization method:** Quarternions.

**Algorithms employed:** Wahba’s problem (opti. problem), SVD, Kalman filter (extended, unscented), quarternion error state, B-dot controller, Model predictive control (linear and non-linear),

Project conclusion

**Results:** partial success, most requirements (detumble, two-axis attitude stability relative to local geomagnetic field and attitude determination) were met however, not all were met (Global attitude acquisition).

**Shortcomings:** linear MPC does not work well enough with magnetorquers on a short predicition horizon, and non-linear MPC for 3-axis stability was too complex at the time for the group to complete

**Possible Improvements:** better components, less strict requirements compared to actual AAUSAT3 mission. “hardware on the loop” approach = test algorithms onboard the hardware and satellite environment tested in simulation.

**Extra interesting notes:** The use of permanent magnets and magnetorquers at the same time. Utilizing MPC in a system only using magnetorquer actuation has not (to the groups knowledge) been done before.

### **Title**: Attitude Control and Fault Detection for AAUSAT3 **Year:** 2010

Satellite information

**Satellite:** AAUSAT3

Problem to solve

**Problem Statement:** How to develop a Fault Detection and Isolation (FDI) and Control for the ADCS system of the AAUSAT3?

**Subsystem to design:** ADS, Pointer controller, Detumble controller, Fault Detection and Isolation (FDI)

Solution definition

**Sensors & Actuators:** Magnetometers, sun sensors, gyroscopes, magnetorquers and temperature sensor, GPS, permanent magnet

**Parametrization method:** Quaternions

**Algorithms employed:**

* B-dot Controller (For detumbling the satellite)
* A Linear Quadratic Regulator (For inertial and nadir pointing controllers)

Project conclusion

**Results:** Both the inertial and nadir pointing controller are able to hold the satellite below an error angle of 50◦ 90% of the time. The Fault Detection and Isolation (FDI) is able to detect all the tested simulated faults, but not all faults were isolated correctly and some detection times did not satisfy the requirement.

**Shortcomings:** Difficulty in detecting faults during eclipse periods and isolating problems with magnetorquers.

**Possible Improvements:** Upgrade the FDI model or develop a more effective method to precisely identify and isolate faults. Ensure controllers can be adjusted post-launch based on in-flight performance.

**Extra interesting notes:** 8. Semester

### **Title:** AAUSAT 3 ADCS **Year:** 2008

Satellite information

**Satellite:** AAUSAT3

Problem to solve

**Problem Statement:** N/A (chapter 2.4 states: “The final goal is to design and implement an attitude determination and control system for AAUSAT3.”.)

**Subsystem to design:** ADCS, magnetorquer design and control (PID).

Solution definition

**Sensors & Actuators:** Gyroscope, Magnetometer, photodiodes, star tracker, NAVSTAR global position system (GPS), Magnetorquer

**Parametrization method:** newtonian dynamics & kinematics??

**Algorithms employed:** Classical control theory (PID)

Project conclusion

**Results:** They produced a proof of concept using a 1-D model, which was successful. Extrapolates a 3-D model will be successful, using a full system.

**Shortcomings:** problems concerning components intended to be used in the project resulting in much time spent on making new components, much time spent on coordination with other groups working on AAUSAT and members of SATLAB.

**Possible Improvements:**

**Extra interesting notes:**

### **Title:** Attitude Control system for AAU CubeSat - MSc **Year:** 2002

Satellite information

**Satellite:** AAUSAT1

Problem to solve

**Problem Statement:** N/A (Primary mission: To show capability of designing and building a spacecraft and hereby gaining experience in designing small satellites in particular.)

**Subsystem to design:** ADS, ACS, Command and Data Handling System (CDHS)

Solution definition

**Sensors & Actuators:** Magnetorquer, Magnetometer, Sun/temperature sensor

**Parametrization method:** Quaternions

**Algorithms employed:**

* B-dot controller (For detumbling)
* A constant gain controller based on periodic optimal control (For nadir and inertial pointing stability)

Project conclusion

**Results:** Simulations of the control algorithms with nonlinear model of the satellite proved, that the required pointing accuracy is achievable with a pass directly over Denmark.

**Shortcomings:**

* Hardware: Power consumption issue in magnetorquers.
* Control: Initial convergence issues resolved, but challenges with different references.
* Software: Incomplete testing, especially control algorithm integration.

**Possible Improvements:** Fix the shortcomings.

**Extra interesting notes:**

* They tried a controller derived from LMI for nadir and inertial pointing stability, but it was worse that constant gain controller so they didn’t use it.
* Master thesis with supervisor being Rafael Wisniewski

### **Title:** Attitude Determination for AAU CubeSat - BSc **Year:** 2002

Satellite information

**Satellite:** AAUSAT1

Problem to solve

**Problem Statement:** N/A

**Subsystem to design:** ADS

Solution definition

**Sensors & Actuators:** Sun sensors, magnetometer , temperatur sensors, magnetorquers

**Parametrization method:** Quaternions

**Algorithms employed:** Wahba’s Problem, The Optimal Two Observation Quaternion Estimation Method

Project conclusion

**Results:**

* The deterministic algorithm gave a attitude accuracy below 8 deg; velocity determination needs further development.
* The accuracy of the EKF was best when using only magnetometer data where attitutude error was approximately ± 2 deg.
* Convergence was fastest when also using sun sensor data; initializing with deterministic attitude determination achieved fast convergence (error never exceeding 15 deg, settling at approximately ±2.5 deg).
* Algorithm accuracies met the 8 deg requirement, but ACS inclusion in future tests is necessary to confirm pointing accuracy.

**Shortcomings:**

* A table with text and numbers

  Description automatically generatedPending assembly, testing, and calibration for sun sensors, ADCS print, and magnetometer.

**Possible Improvements:** Make ACS

**Extra interesting notes:**

The table 10.1

### **Title:** Evaluation of EMPC for Attitude Control of AAUSAT3 **Year:** 2010

Satellite information

**Satellite:** AAUSAT3

Problem to solve

**Problem Statement:** N/A

**Subsystem to design:** ACS

Solution definition

**Sensors & Actuators:** Magnetorquers

**Parametrization method:** Quaternions

**Algorithms employed:** Explicit Model Predictive Control (EMPC)

Project conclusion

**Results:** EMPC is not a good controller for the real system, it is unstable in the real system.

**Shortcomings:** Mathematical complexity and low robustness

**Possible Improvements:** N/A Just use normal control methods

**Extra interesting notes:**

This paper contains a lot of juice to be extracted in this topic.

### **Title:** Estimating Spacecraft Attitude Based on in-orbit Sensor Measurements **Year:** -

Satellite information

**Satellite:** AAUSAT3

Problem to solve

**Problem Statement:** N/A

**Subsystem to design:** ACS

Solution definition

**Sensors & Actuators:** Orbit is measured, sun and magnetic field directions are computed from this. Angular velocity == gyroscope

**Parametrization method:**

**Algorithms employed:** SVD (Whaba’s algorithm) and EKF (Runge-Kutta 4th order approx. method)

Project conclusion

**Results:** In-orbit error:

|  |  |  |
| --- | --- | --- |
|  | MAX | AVG |
| EKF | 14.9 | 4.2 |
| SVD | 3.9 | 2.1 |

SVD is more sensitive in general to noise, but it outperforms the EKF.

**Shortcomings:** The EKF does not include a model of the disturbances, which renders it really inneficient

**Possible Improvements:**  Include the most important disturbances in the EKF model

**Extra interesting notes:**

SVD seems like an algorithm to take into consideration for ADS.

### **Title**: Attitude Determination and Control System for AAUSAT 3 **Year:** 2010

Satellite information

**Satellite:** AAUSAT3

Master thesis

Problem to solve

**Problem Statement:**

**Subsystem to design:**

Solution definition

**Sensors & Actuators:** Magnetorquers, magnetometers, sun sensors, gyroscopes and permanent magnet.

**Parametrization method:** Quaternions

**Algorithms employed:**

ADS: Unscented Kalman Filter (UKF),(SVD)

ACS: B-dot for detumbling, 3-axis stabilization with magnetorquers.MPC, NMPC, permanent magnet stabilization

Project conclusion

**Results:** ADS: +-4deg, +-9 in eclipse

Detumbler: 3 orbits stabilization

ACS: The MPC is not good for magnetorquers.

**Shortcomings:** Employed components were not good quality

**Possible Improvements:** NMPC with magnetorquers

**Extra interesting notes:**

Contains deeps explanation of sensors choice

### **Title:** Attitude Determination System for AAUSAT 2 **Year:** 2004

Satellite information

**Satellite:** AAUSAT 2

Problem to solve

**Problem Statement:** N/A Design the AAUSAT 2 objectives and the ADCS requirements for it

**Subsystem to design:** Whole ADS: Sensors usage, attitude estimation, consideration fo torques, magnetic and orbit models, …

Solution definition

**Sensors & Actuators:** Magnetorquers, flywheels. Magnetometers, gyroscope, solar panels

**Parametrization method:**

**Algorithms employed:**  Sensor fault detection

ADS: This is to be checked, pure gold

-Q-method: Apply whaba’s algorithm to the attitude matrix, but express it its quaternion formulaton. Deterministic model. Can adapt to faulty sensors

-EKF: Uses Runge-Kutta 4th order approx. method and the results of the Q-method. Assumes Stochastic model

Project conclusion

**Results:** The EKF works nicely, but the real system does not work. Presummed errors in the implementation of the q-method or sensors.

**Shortcomings:** Too complex of a system to properly test everything

**Possible Improvements:** Recheck their project with appropriate understanding and check their testing setup, to identify errors.

**Extra interesting notes:**

AAUSAT 2 started in 9-2003.

AAUSAT 1 started in 2001, launched the 30th June 2003

### **Title:** Fault Detection and Isolation in Sensors and Actuators used for Attitude Control **Year:** 2006

Satellite information

**Satellite:** AAUSAT2

Problem to solve

**Problem Statement:** N/A Improve the ACS de

**Subsystem to design:** ACS as a fault tolerant system (FTS)

Solution definition

**Sensors & Actuators:** Magnetometers, gyros, sun sensors.

**Parametrization method:** quaternions

**Algorithms employed:**

ADS: Optimal two- observation quaternion estimation algorithm

Project conclusion

**Results:**

**Shortcomings:**

**Possible Improvements:**

**Extra interesting notes:**

Expected launch 2006

### **Title:** Attitude Control System for CubeSat[[3]](#footnote-4) **Year:** 2008

Satellite information

**Satellite:** AAUSAT3

Problem to solve

**Problem Statement:** How can an ADCS for AAUSAT3 be designed so that the system complies with AAUSAT3's requirements? And can the effect of the system be demonstrated in the laboratory?

**Subsystem to design:** ADC and ACS

Solution definition

**Sensors & Actuators:** Magnetometer, coils (Helmholtz cage)

**Parametrization method:** None

**Algorithms employed:** None, the project focused on Analogue Circuit Design

Project conclusion

**Results:** Their ADS didn’t work thus they couldn’t test their ACS.

**Shortcomings:** Helmholtz coil only control 1-axis at a time.

**Possible Improvements:** Include simulations with matlab and try to get results of the ADS and ACS since it didn’t work in practice. Understand Attitude and how to parametrize, use an algorithm.

**Extra interesting notes:** 2. Semester, Danish rapport. The ACS uses 4 coils to control the satellite with the help of the earth’s magnetic field.

### **Title:** Fault Tolerant Control of AAUSAT2 **Year:** 2006

Satellite information

**Satellite:**

Problem to solve

**Problem Statement:**

**Subsystem to design:**

Solution definition

**Sensors & Actuators:** Same as other AAUSAT 2

**Parametrization method:** quaternions,

**Algorithms employed:**

ACS: State feedback control (magnetorquers) with static LQR. Periodic theory design

State feedback control (flywheels) with static LQR. Magnetic desaturation also implemented.

B-dot controller: 80-20% actuation-sensing

Project conclusion

**Results:** Magnetorquers: System stabilizes to 1deg error (no PI, this is prob not true in real case) ts = 17500s, even when 1 of them fails. It takes 3 orbits. With only 2 magnetorquers, it is still stable, but it takes around 4 orbits to stabilize, or around 6h.

Flywheel + magn: 1 degree error, ts = 428s

B-dot: Works,

**Shortcomings:** No PI employed, so the error won’t be as stated. Faulty constant magnetorquers cause the system to destabilize. Flywheels can only rotate up to 45º.

**Possible Improvements:**

**Extra interesting notes:**

Contains a definition of the actual ADCS!!!! So, over the control methods, all the required faulty control and decision logic.

### **Title: [[4]](#footnote-5)Attitudecontol of AAUSAT3** **Year:** 2009

Satellite information

**Satellite:** AAUSAT3

Problem to solve

**Problem Statement:** (chapter 1.1 has multiple problem statements, collectively focussing on making an ACDS for picosatellites for surveillance of the Greenlandic waters.)

**Subsystem to design:** ADS, ACS, Circuit design of systems, classical control (PID)

Solution definition

**Sensors & Actuators:** Magnetometer, Electromagnetic coils (magnetorquers?)

**Parametrization method:** N/A

**Algorithms employed:** PID control

Project conclusion

**Results:** 7 out of 8 requirements met (Detumbling failed within given timeframe). ADS and ACS was successfully tested. All tests were made through test setup in a Helmholtz-cage.

**Shortcomings:** Model only made for 1-axis. Needs to be fully modelled for use in space. Only uses magnetometer as a sensor, and magnetorquers as actuators.

**Possible Improvements:** 2. Semester project so most improvements are towards the report and content of methods used.

**Extra interesting notes:**

### **Title:** Optimal Hybrid Control for AAUSAT-II **Year:** 2005

Satellite information

**Satellite:** AAUSAT2

Problem to solve

**Problem Statement:** None (To create an optimal hybrid controller to handle the scheduling of desaturation needed for momentum wheels to lower the energy consumption of the system).

**Subsystem to design:** ADS and ACS

Solution definition

**Sensors & Actuators:** Magnetorquers, biased momentum wheels,

**Parametrization method:** Quaternions

**Algorithms employed:**

* LQR-controller
* Desaturation controller

Project conclusion

**Results:** Detumbling works well within one obit. Issues with generating a model predictive controller (MPC) thus not being able to simulate and verify the optimal hybrid controller

**Shortcomings:** Simulation issues that requires alternating the multi parametric toolbox (MPT) or reconfiguring the HYDSEL model (abstract modelling language called HYDSEL).

**Possible Improvements:** Fixing MPC so that one can simulate and verify the optimal hybrid controller for the AAUSAT2 satellite.

**Extra interesting notes:** 9. Semester

### **Title:** Attitude Control System for the MONS-Ballerina Satellite **Year:** 2000

Satellite information

**Satellite:** MONS-Ballerina Satellite

Problem to solve

**Problem Statement:** N/A

**Subsystem to design:** Only the pointing mode, actuators

Solution definition

**Sensors & Actuators:** Star Imagers, sun sensors, magnetometer. Magnetorquers, 4 momentum wheels

**Parametrization method:** quaternions

**Algorithms employed:** SS PI controller for both the WATCH flywheels and the attitude controller, with static LQR.

Project conclusion

**Results:** 20’’ RMS pointing accuracy accomplished with 10’’ RMS.

**Shortcomings:** N/A

**Possible Improvements:** N/A

**Extra interesting notes:**

Contains linearization examples for both the kinematics and dynamics of a satellite.

### **Title: Robust Disturbance Rejecting Attitude Control** **Year:** 2006

Satellite information

**Satellite: North Sea Observer**

Problem to solve

**Problem Statement:** N/A (A Description of Objective is on page 5)

**Subsystem to design:** Detumbling, Pointing, Desaturation, Sun Pointing and Pointing with electromagnetic actuation.

Solution definition

**Sensors & Actuators:** Momentum wheel, Magnetorquers, Sun sensor, Gyro and Magnetometer

**Parametrization method:** Quaternions

**Algorithms employed:** B-Dot controller(Detumbling), LQR-controller(Pointing and Sun Pointing), Kalman filter, Linear Matrix Inequalities, State Feedback Controller(Angular Velocity controller), CCPL controller(NSO magnetorquers), ILQR-controller(Attiude controller), Monte Carlo simulation(Reliability of ACS)

Project conclusion

**Results:** CCPL < ILQR they conclude LQR is the preferred method for designing a controller for attitude. Error angle of less than 0,1761 for a confidence interval of 95% for the ACS. Attitude controller was capable of maintaining an attitude of 0,0174 degrees.

**Shortcomings:**

**Possible Improvements: An improvment to the 2 degree z-axis error angle above target could maybe be improved with increased bandwidth which would require higher sample rate. They have a “Future Work” chapter 10.3 page 80.**

**Extra interesting notes: Their Appendix are very comprehensive in the theory used and could be very helpful, and it has a Simulation Environment with figures of their diagrams used in simulink 10. Semester**

### **Title:** A Fault tolerant Control Supervisory System development Procedurefor Small Satellites **Year:** 2007

Satellite information

**Satellite:** AAUSAT2

**Type:** Paper

Problem to solve

**Problem Statement:** Definition of how to develop a fault tolerant ADCS

**Subsystem to design:** N/A

Solution definition

**Sensors & Actuators:** N/A

**Parametrization method:** N/A

**Algorithms employed:** N/A

Project conclusion

**Results:** Useful and concise introduction to the topic of fault tolerant control.

**Shortcomings:** N/A

**Possible Improvements:** N/A

**Extra interesting notes:**

Contains references to useful books related to Fault Tolerant Design.

### **Title:** **Year:**

Satellite information

**Satellite:**

Problem to solve

**Problem Statement:**

**Subsystem to design:**

Solution definition

**Sensors & Actuators:**

**Parametrization method:**

**Algorithms employed:**

Project conclusion

**Results:**

**Shortcomings:**

**Possible Improvements:**

**Extra interesting notes:**

1. **Danish translation of: “Testbænk til CubeSats med attitudekontolsystem baseret på magnetorquers”.** [↑](#footnote-ref-2)
2. The “satellite trap” is a satellite frame with magnetorquers used to simulate the satellite in orbit. [↑](#footnote-ref-3)
3. In Danish: “Attitudestyresystem til CubeSat. [↑](#footnote-ref-4)
4. Danish translated report: ”Attitudekontrol af AAUSAT3” [↑](#footnote-ref-5)