PURDUE UNIVERSITY | School of Aeronautics and Astronautics

Engineering Faculty Document No. 115-25

January 29, 2025

Memorandum

To: The Faculty of the College of Engineering

From: The School of Aeronautics and Astronautics

Date: January 29, 2025

Re: New Graduate Course, **AAE 54100 Attitude Determination & Control**

The faculty of the School of Aeronautics and Astronautics have approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

Course no. **AAE 54100 Attitude Determination & Control**
Fall alternating years, Lecture, Cr. 3

Description: The course covers the fundamentals, basic techniques, and concepts of attitude determination and control based on first principles. Those fundamentals are subsequently applied to the attitude problem of a spacecraft on orbit. The course includes knowledge, modeling and understanding of on-board sensors and actuators, their outputs and error profiles, and the static attitude determination methods from those. Furthermore, dynamic attitude determination methods are taught. Different types of control methods and controller designs are introduced, compared, and evaluated.

Reason: The course is based on the undergraduate coursework on general dynamics including the attitude dynamics (AAE 34000) and understanding of the attitude space and its suitable representations (AAE 44000). It enables students to actively understand and control a six-degree of freedom system, design sensor and actuator suites for given requirements and to design attitude determination and control for those. A focus is the robustness of the methods, enabling autonomy based on an understanding of the errors inherent to sensors and actuators and their mathematical representation.

The course fills a crucial existing gap in the curriculum, where attitude dynamics (which forces create torques on the satellite) is taught but students are not enabled to determine the attitude of a spacecraft or control its attitude, which is an integral and necessary part of any spacecraft mission. Attitude space is fundamentally different from general linear (Cartesian) space, necessitating different representations of states and errors and controller design.

William A. Crossley
Uhrig & Vournas Head of Aeronautics and Astronautics
Professor of Aeronautics and Astronautic

Willi A. Crossley

Digitally signed by William A Crossley
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SCHOOL OF AERONAUTICS AND ASTRONAUTICS
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Enrollment History – Previously taught as AAE 590 Attitude Determination & Cntrl

Enrollment			2023 Spring	2024 Fall	**Total**
Attitude Determination & Cntrl	AE - School of Aero and Astro Engr	AAE - Aero & Astro Engineering	12	2	**14**
	GR - Graduate	AAEN - Aeronautics & Astronautics	13	8	**21**
			25	**10**	**35**

Syllabus

Contact information

Carolin Frueh (pronounced: ”free”) *she/her/hers*, `cfrueh@purdue.edu`

Course Overview

The course covers the fundamentals, basic techniques, and concepts of attitude determination and control based on first principles. Those fundamentals are subsequently applied to the attitude problem of a spacecraft on orbit. The course includes knowledge, modeling and understanding of on-board sensors and actuators, their outputs and error profiles, and the static attitude determination methods from those. Furthermore, the methods of dynamic attitude determination methods are taught. Different types of control methods and controller designs are introduced, compared and evaluated.

The class is open to senior undergraduate students and counts as Astrodynamics and Space Applications area for them.

Course Goals

The goals of this course are:

- ability to model on-board attitude sensors and actuators including their error characteristics on various fidelity levels, understanding of their capabilities and limitations and being able to calibrate them for use.
- competent in performing static attitude determination using various sensor suites
- competence in performing dynamic, non-static attitude determination using various sensor suites
- ability to define sensing setup for a given attitude determination requirement.
- ability to design on-board attitude controllers for given actuators for various robustness levels, understanding of strengths and draw-backs of different controllers.
- application of the theoretical knowledge to real-world attitude determination and control problems.

Course Outcomes

At the completion of the course, the students have a fundamental understanding of the challenges, limitations and requirements of on-board real-time attitude determination and control in a full six degree of freedom environment. They are aware of the design space of on-board sensors and actuators, the various error involved in both, and how to answer those in the attitude determination and controller design. The students have expanded their capabilities to present and communicate technical content.

Topics and Schedule

1. *week 1* Recap: Attitude Representations and Derivation of Quaternion Relations
2. *week 2* Attitude Error Representations in the Direction Cosine Matrix and the Quaternion Representation
3. *week 3 and 4* Static Attitude Determination (SAD): Whaba's Problem
   (a) *week 3* SAD: TRIAD, Davenport's q method, QUEST
   (b) *week 4* SAD: Error Analysis in Whaba's Problem: The error vector (QMM) and covariance
4. *week 5* Sensors: Star trackers, Sun Sensors, Gyros, Magnetometer
5. *week 6* Gyro measurement model
6. *week 7* Recap: Attitude Kinematics and Dynamics
7. *week 8 through 10* Dynamic Attitude Determination - Estimation (DAD)
   (a) *week 8* DAD: Additive Quaternion Representation
   (b) *week 9* DAD: Multiplicative Extended Kalman Filter without calibration
   (c) *week 10* DAD: Multiplicative Extended Kalman Filter including calibration
8. *week 11* Actuators: Inertial Measurement Unit, Reaction Wheels, Magnetotorquers, Thrust and their error models
9. *week 12 through 15* Attitude Control (AC)
   (a) *week 12* AC: General Formulation and Limits
   (b) *week 13* AC: Tracking Attitude Control
   (c) *week 14* AC: Detumbling and Momentum Dumping
   (d) *week 15* AC: Effects of Noise
10. *week 16* Final Project Presentations

Required Course Materials

The class is largely based on the book from F. Landis Markley and John L. Crassidis, Fundamentals of Spacecraft Attitude Determination and Controlm but a comprehensive course script with all required materials is provided.

The use of and coding in Matlab is required for this course; a student edition is sufficient.

Grading

70% homework
30% final project (presentation, project report, interaction Q&A)
No final exam.

Letter grades are assigned at the end of the semester ranging from A+ to F.

Copyright, Sources, AI, and Large Language Models

All course materials are copyright protected. Students are free to use them as part of the class. Distribution is only permitted with instructor approval. Uploading materials on webshare sites (e.g., CourseHero) is explicitly prohibited.

The use of all sources used in homework, and project have to be explicitly declared.

The use of AI and Large Language Models (e.g., ChatGPT, BERT, PaLM, Gemini, T5, Turing NLG....) is not permitted unless explicitly stated.

Homework Guidelines

The homework document is to be handed in via Gradescope.

Final Project

For the final project two options exist:
Option a: The selection of a relevant publication with respect to the topics of the class. The publication has to be shown to Prof. Frueh for approval prior to start working on the project. You cannot be an author or be mentioned in the acknowledgments of the selected paper. Results of the chosen publication are to be reproduced.

Option b: Designing, implementing and evaluating an experimental setup for attitude control using materials taught in the class. Experimental setup idea has to be run by Prof. Frueh for approval prior to start working on the project. It cannot be an experiment that you are using in another class or have used unaltered or largely unaltered in other prior classes.

The final project consists of the parts of giving a presentation, and a final report.

A presentation and report has to consist *at minimum* of the following parts:

1. Introduction to the topic
2. Justification of the research
3. Context of the publication or the experiment and research content (other publications)
4. Explanation of the methodology and results of the paper or the experiment
5. Comparison of your reproduced results with the results stated in the paper or the results expected of the experiment
6. Your comments and observations on the research and the comparison
7. Conclusions

Presentations time for each person is limited to no more than 10 minutes and has to be handed in via Gradescope by: **Dec 2, 11:00pm**.

In addition, a final project report between 10 and 30 pages long, and (as additional file(s), not counting towards the page limit) the code used to generate your results, is to be handed in by:
Dec 6, 11:00pm

The presentation itself including Q&A take place in the last week of class on Dec. 3 and Dec. 5. **Attendance during the final project presentations of all students is mandatory**.

Boilermaker Pledge, Diversity and University Resources

As a boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together - we are Purdue.

Nondiscrimination Statement and Reporting
Purdue University is committed to maintaining a community which recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. More details are available on our course Brightspace table of contents, under University Policies.

The School of Aeronautics and Astronautics is also committed to a climate of inclusion; if you need to report an issue of hate or bias, you may use the link at the top right of our page here: `https://engineering.purdue.edu/AAE/aboutus/Diversity/index_html`

Mental Health
If you find yourself beginning to feel some stress, anxiety and/or feeling slightly overwhelmed, try Therapy Assistance Online (TAO), a web and app-based mental health resource available courtesy of Purdue Counseling and Psychological Services (CAPS). TAO is available to all students at any time by creating an account on the TAO Connect website, or downloading the app from the App Store or Google Play. It offers free, confidential well-being resources through a self-guided program informed by psychotherapy research and strategies that may aid in overcoming anxiety, depression and other concerns. It provides accessible and effective resources including short videos, brief exercises, and self-reflection tools.

If you need support and information about options and resources, please contact or see the Office of the Dean of Students. Call 765-494-1747. Hours of operation are M-F, 8 a.m.- 5 p.m.

If you find yourself struggling to find a healthy balance between academics, social life, stress, etc., sign up for free one-on-one virtual or in-person sessions in West Lafayette with a Purdue Wellness Coach at RecWell. Student coaches can help you navigate through barriers and challenges toward your goals throughout the semester. Sign up is free and can be done on BoilerConnect. Students in Indianapolis will find support services curated on the Vice Provost for Student Life website. If you're struggling and need mental health services: Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of mental health support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at 765-494-6995 during and after hours, on weekends and holidays, or by going to the CAPS offices in West Lafayette or Indianapolis.

Academic Integrity
Academic integrity is one of the highest values that Purdue University holds. Individuals are encouraged to alert university officials to potential breeches of this value by either emailing `integrity@purdue.edu` or by calling 765-494-8778. While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern.

Emergency Preparedness and Readiness
See the separate document posted on Brightspace in the Emergency Preparedness and Readiness folder.