EN.525. 661 section 81 Syllabus

UAV Systems and Control

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Course Information

Course Information:

UAV Systems and Control
EN.525. 661 81 (3.0 Credits)
Spring 2024 [AE Spring 2024]

Description
This hardware-supplemented course covers the guidance, navigation- and control principles common to many small fixed-wing and multirotor unmanned aerial vehicles (UAVs). Building on classical control systems and modeling theory, students will learn how to mathematically model UAV flight characteristics and sensors, develop and tune feedback control autopilot algorithms to enable stable flight control, and fuse sensor measurements using extended Kalman filter techniques to estimate the UAV position and orientation. Students will realize these concepts through both simulation and interaction with actual UAV hardware. Throughout the course, students will build a full 6-degree-of-freedom simulation of controlled UAV flight using MATLAB and Simulink. Furthermore, students will reinforce their UAV flight control knowledge by experimenting with tuning and flying actual open-source quadrotor UAVs. Prerequisite(s): Background in control systems (e.g., EN.525.609 Continuous Control Systems) and matrix theory along with a working knowledge of MATLAB. Experience using Simulink is desired. Existing familiarity with C programming language, electronics, and microcontrollers will be helpful but is not required.

Department: PE Electrical and Computer Engineering
College: Engineering and Applied Science Programs for Professionals

Expanded Course Description:

Prerequisites

Background in control systems (e.g., 525.609 Continuous Control Systems) and matrix theory along with a working knowledge of MATLAB. Experience using Simulink is desired. Existing familiarity with C programming language, electronics, and microcontrollers will be helpful but is not required.

Instructor Information:

Instructors

Jeffrey Barton
jbarto10@jhu.edu

Joey DiGirolamo
ldigiro1@jhu.edu

Communication Policy:

Jeff Barton

Work: 240.228.4548

Cell: 410.294.6990

E-mail: jbarto10@jhu.edu

Joey DiGirolamo

Work: 240.228.1443

Cell: 610.844.2745

E-mail: ldigiro1@jhu.edu

We prefer that students contact us via email directly using the email addresses listed above, rather than through Canvas. We will make every effort to respond to your inquiry within 48 hours or earlier.

Office Hours:

For more information regarding Zoom, please see the Zoom Information page located in **Support** on the left menu.

Upon request each week, this course will use Zoom to facilitate weekly, synchronous office hours at 7:30pm (Eastern) on Monday evenings via the Office Hours link on Canvas. You are not required to participate in office hours; however, you may find them very beneficial for receiving more timely answers to questions related to the course content and assignments.

If you wish for us to hold office hours during a particular week, please send an email request at least an hour before the scheduled time.

Course Structure:

The course materials are divided into modules which can be accessed by clicking Course Modules on the left menu. A module will have several sections including the overview, content, readings, discussions, and assignments. You are encouraged to preview all sections of the module before starting. Most modules run for a period of seven (7) days, exceptions are noted in the **Course Outline**. You should regularly check the **Calendar** and **Announcements** for assignment due dates.

Course Topics:

- Vector Geometry, System Modeling
- Control Systems, Vector Operations, Rotating Coordinates, Vector Differentiation
- Kinematics, Dynamics, Equations of Motion
- Forces & Moments, Gravity, Aerodynamics

- Propeller Modeling, Scalar Equations of Motion, Trim, Linearization, Aircraft Response Modes
- Winds & Gusting, Autopilot Control Structure, Manual Autopilot Tuning
- Linear Response Models, Roll Autopilot
- Analytically Derived Autopilot Tuning
- Waypoint Control, Sensors
- State Estimates, Kalman Filter Introduction
- State Estimates using Extended Kalman Filters
- Quadcopter Modeling
- Quadcopter Flight Software
- Gimbaled Cameras

Course Goals:

The overall objective of the course is to gain an understanding of UAV modeling, flight control, and state estimation. This will be accomplished by learning how to model UAV dynamic motion in a 6DOF simulation, as well as developing and implementing flight control and state estimation algorithms in the simulation. Furthermore, we will use an open source quadcopter to reinforce these lessons.

Course Learning Outcomes (CLOs):

- Create a six degree of freedom simulation of a fixed wing aircraft and quadcopter. (Model fixed wing aircraft and quadcopter kinematics; Model fixed wing aircraft and quadcopter aerodynamics.; Model propeller propulsion.; Model fixed wing aircraft and quadcopter sensors.)
- Design and implement an autopilot for a fixed wing aircraft and quadcopter.
- Design and implement state estimation for a fixed wing aircraft and quadcopter
- Implement an autopilot on a UAV microprocessor.
- Implement state estimation on a UAV microprocessor.

Required Text and Other Materials

Textbooks:

Beard, R.W. & McLain, T.W. (2012). *Small unmanned aircraft: Theory and practice* (1st ed.). Princeton, NJ: Princeton University Press.

ISBN-10: 0691149216

ISBN-13: 978-0691149219

Textbook information for this course is available online through the appropriate bookstore website: For online courses, search the BNC website at http://ep.jhu.edu/bookstore.

Access to textbooks via the JHU Libraries:

EP students may access electronic versions of textbooks through the Sheridan Libraries. Instructions on how to search for available textbooks are accessible through this link: Browse Electronic Textbook Instructions

Required Software:

MATLAB

You will need access to a recent version of MATLAB with Simulink and the Control Systems Toolbox. The MATLAB Total Academic Headcount (TAH) license is now in effect. This license is provided at no cost to you. Send an email to software@jhu.edu to request your license file/code. Please indicate that you need a standalone file/code. You will need to provide your first and last name, as well as your Hopkins email address. You will receive an email from Mathworks with instructions to create a Mathworks account. The MATLAB software will be available for download from the Mathworks site.

Hardware Related Software

Arduino IDE 1.8.5

Teensyduino 1.41

Teensy Loader

The Flybrix App

You will need to download several pieces of open source software to complete the hardware related tasks for the class. Installation instructions will be presented in Module 2. All software is functional on a system with Windows XP or newer, or Mac OS-X 10.7 or newer. The Flybrix App is available for free in the iTunes or Google Play store. If you do not have a device capable of hosting the app, please alert us and accommodations can be made.

Hardware Requirements

The supplemental hardware for this class is the Flybrix Quadcopter Kit and a test stand to help with experimentation.

If you are a student who lives within 30 miles of Johns Hopkins University Applied Physics Laboratory, you may be expected to come pick up your hardware in person before Module 3. Please e-mail us your mailing address, and we will determine who will need to pick up their kits. Kits can be picked up at Montpelier 7 (MP7) Room 150, 7710 Montpelier Rd, Laurel, MD 20723. Hours are 8:00 AM – 10:00 PM Monday through Thursday, and 8:00 AM to 4:30 PM Friday. Before you make the trip, please alert us that you are doing so. You will either pick your kit up from Tracy Gauthier (Room 150), or we will leave the kit outside of her office with a post-it note on it.

If you live farther than 30 miles away, you will receive your hardware kit via FedEx before Module 3. You should keep the shipping box and the return box. At the end of the semester, please return the kit via FedEX in the return box. Fill out the return box as follows:

- In box 3 use address: JHU-APL 11100 Johns Hopkins Road, MP7-150 Laurel, MD 20723
- In box 3 put the recipient: Tracy Gauthier

- In box 1 fill out your address
- Box 2 can be left blank
- Select “FedEx Express Saver” in box 4
- Select “FedEx Box” in box 5
- Select “No Signature Required” for box 6, and select “No” for question “Does this shipment contain dangerous goods”
- Select “Recipient” in box 7 for billing information and fill in the FedEx Account number in the line below: 254340782

If there are any extenuating circumstances please let us know, and we will work with you to ensure you receive the kits.

As stated in the previous section, a computer running Windows XP or newer and Mac OS-X 10.7 or newer is required for this course. In addition, the computer must have a USB port and an SD card reader to complete hardware-related modules. Finally, a device capable of hosting the Flybrix App and Bluetooth enabled is highly recommended.

Technical Requirements:

You should refer to General Technical Requirements for guidance on system requirements. Access support resources from the **Help** menu if you encounter any technical issues.

Evaluation and Grading

Student Coursework Requirements:

Please be aware that this course has a heavy workload, though prior students have felt the effort worthwhile. Make sure that you will have sufficient time to devote to the course.

It is expected that each module will take approximately 9–14 hours per week to complete. Here is an approximate breakdown: reading the assigned sections of the texts (approximately 1–2 hours per week) as well as some outside reading/research, listening to the audio annotated slide presentations (approximately 2–3 hours per week), and homework/hardware/project assignments (approximately 6–9 hours per week).

This course will consist of the following basic student requirements:

Discussions (5% of Final Grade Calculation)

You are responsible for responding to weekly discussion prompts which should be completed before the end of each module week. You are also responsible for providing interactions (e.g., thoughtful responses or comments) to at least two of your classmates for each of these prompts. Grading of these prompted responses and discussions will be based on timeliness, display of critical thinking, and civil discourse. Feel free to agree or disagree with your classmates (and/or teachers), but please ensure that your postings are civil and constructive.

Assignments (65% of Final Grade Calculation)

Weekly assignments will include relevant academic exercises and the development of a 6-degree-of-freedom fixed-wing UAV simulation. **Assignment submissions should be well organized and legible, figures and tables should be captioned and labeled appropriately, and explanations should show a thoughtful proof of understanding.** Also include your name and a page number indicator (i.e., page x of y) on each page of your submissions. **Adobe ".pdf" file submissions are preferred**, but MS Word documents are acceptable. **The name of the submitted file should contain your last name (e.g. Barton_Mod4.pdf)**.

All assignments are due according to the dates in the Calendar. **Submissions must reflect individual effort.**

Homework assignments build off of each other from week to week, so timely submissions are important. Late submissions will be reduced by 10% for each day late (no exceptions without prior coordination with the instructors). **If you have circumstances that will cause you to be late submitting a particular assignment, you must email us an extension request before the due date with a valid reason and an expected submission date.**

Weekly assignments will be equally weighted in the calculation of the final grade.

Reinforcement Assignments with Hardware (5% of Final Grade Calculation)

Throughout the course there will be reinforcement assignments using the Flybrix open source quadcopter that will be provided to you. Examples include: experimenting with the physical feel of propeller forces and moments, quadcopter tuning, logging and analyzing quadcopter sensor measurements, feeding quadcopter measurements through offline state estimation algorithms, etc. These assignments and activities are only worth a small portion of the final grade because dealing with hardware can be a challenging and daunting task for some. **However, keeping up with these assignments will be necessary for completing the Quadcopter Hardware Design Project at the end of the semester.** Late penalty: 10% per day unless extension requested and granted prior to due date.

Quadcopter Simulation Design Project (15% of Final Grade Calculation)

For the Quadcopter Simulation Design Project, you will utilize the methodologies learned in developing a fixed- wing 6DOF simulation to develop a complete 6DOF simulation of a quadcopter. The project will be assigned during the week of Module 12 and will be due during the week of Module 13. Late penalty: 10% per day unless extension requested and granted prior to due date.

Quadcopter Hardware Design Project (10% of Final Grade Calculation)

For the Quadcopter Hardware Design Project, you will modify existing flight control and state estimation algorithms on the Flybrix microprocessor using methods learned in the course. You will provide evidentiary material including code, Flybrix flight logs, and representative plots. The project will be assigned during the week of Module 13 and will be due by the end of the week of Module 14. (Thus, the Simulation and Hardware design project efforts will overlap by one week.) Late penalty: 10% per day unless extension requested and granted prior to due date.

Grading Policy:

Assignments are due according to the dates posted in your Canvas course site. You may check these due dates in the Course Calendar or the Assignments in the corresponding modules. We will post grades within one week after assignment due dates.

We generally do not directly grade spelling and grammar. However, egregious violations of the rules of the English language will be noted without comment. Consistently poor performance in either spelling or grammar is taken as an indication of poor written communication ability that may detract from your grade.

A grade of A indicates achievement of consistent excellence and distinction throughout the course—that is, conspicuous excellence in all aspects of assignments and discussion in every week.

A grade of B indicates work that meets all course requirements on a level appropriate for graduate academic work. These criteria apply to both undergraduates and graduate students taking the course.

Final grades will be determined by the following weighting:

Item	% of Grade
Discussions	5%

Assignments	65%
Reinforcement Assignments with Hardware	5%
Quadcopter Simulation Design Project	15%
Quadcopter Hardware Design Project	10%

Policies

Additional Resources:

Personal Wellbeing

If you are struggling with anxiety, stress, depression or other mental health related concerns, please consider connecting with the Johns Hopkins Student Assistance Program (JHSAP). If you are concerned about a friend, please encourage that person to seek out our services. JHSAP can be reached at 443-287-7000 or https://jhsap.org/

Tutoring Website

Johns Hopkins Engineering for Professionals offers a tutoring connection network that allows students to connect with other Johns Hopkins Engineering students or alumni for tutoring services. This service allows students to search a list of courses to “Find a Tutor” or complete a profile to “Become a Tutor.” More information about this service can be found on the tutoring website (https://tutor.ep.jhu.edu/).

Privacy Policies:

To learn more about how to protect your data and privacy, visit Instructure's privacy policy (Canvas) and JHU's privacy policy.

Canvas Accessibility:

Online courses are taught in the Canvas learning management system. To learn more about how Canvas is designed to be accessible, visit Canvas's accessibility standards

Academic Policies:

Deadlines for Adding, Dropping and Withdrawing from Courses

Students may add a course up to one week after the start of the term for that particular course. Students may drop courses according to the drop deadlines outlined in the EP academic calendar (https://ep.jhu.edu/student-services/academic-calendar/). Between the 6th week of the class and prior to the final withdrawal deadline, a student may withdraw from a course with a W on their academic record. A record of the course will remain on the academic record with a W appearing in the grade column to indicate that the student registered and withdrew from the course.

Academic Misconduct Policy

All students are required to read, know, and comply with the Johns Hopkins University Krieger School of Arts and Sciences (KSAS) / Whiting School of Engineering (WSE) Procedures for Handling Allegations of Misconduct by Full-Time and Part-Time Graduate Students.

This policy prohibits academic misconduct, including but not limited to the following: cheating or facilitating cheating; plagiarism; reuse of assignments; unauthorized collaboration; alteration of graded assignments; and unfair competition. Course materials (old assignments, texts, or examinations, etc.) should not be shared unless authorized by the course instructor. Any questions related to this policy should be directed to EP's academic integrity officer at ep-academic-integrity@jhu.edu.

Students with Disabilities - Accommodations and Accessibility

Johns Hopkins University values diversity and inclusion. We are committed to providing welcoming, equitable, and accessible educational experiences for all students. Students with disabilities (including those with psychological conditions, medical conditions and temporary disabilities) can request accommodations for this course by providing an Accommodation Letter issued by Student Disability Services (SDS). Please request accommodations for this course as early as possible to provide time for effective communication and arrangements.

For further information or to start the process of requesting accommodations, please contact Student Disability Services at Engineering for Professionals, ep-disability-svcs@jhu.edu.

Student Conduct Code

The fundamental purpose of the JHU regulation of student conduct is to promote and to protect the health, safety, welfare, property, and rights of all members of the University community as well as to promote the orderly operation of the University and to safeguard its property and facilities. As members of the University community, students accept certain responsibilities which support the educational mission and create an environment in which all students are afforded the same opportunity to succeed academically.

For a full description of the code please visit the following website: https://studentaffairs.jhu.edu/policies-guidelines/student-code/

Classroom Climate

JHU is committed to creating a classroom environment that values the diversity of experiences and perspectives that all students bring. Everyone has the right to be treated with dignity and respect. Fostering an inclusive climate is important. Research and experience show that students who interact with peers who are different from themselves learn new things and experience tangible educational outcomes. At no time in this learning process should someone be singled out or treated unequally on the basis of any seen or unseen part of their identity.

If you have concerns in this course about harassment, discrimination, or any unequal treatment, or if you seek accommodations or resources, please reach out to the course instructor directly. Reporting will never impact your course grade. You may also share concerns with your program chair, the Assistant Dean for Diversity and Inclusion, or the Office of Institutional Equity. In handling reports, people will protect your privacy as much as possible, but faculty and staff are required to officially report information for some cases (e.g. sexual harassment).

Course Auditing

When a student enrolls in an EP course with “audit” status, the student must reach an understanding with the instructor as to what is required to earn the “audit.” If the student does not meet those expectations, the instructor must notify the EP Registration Team [EP-Registration@exchange.johnshopkins.edu] in order for the student to be retroactively dropped or withdrawn from the course (depending on when the "audit" was requested and in accordance with EP registration deadlines). All lecture content will remain accessible to auditing students, but access to all other course material is left to the discretion of the instructor.