AE 598: Spacecraft Rendezvous and Proximity Operations

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Welcome

Welcome to AE 598, Spacecraft Rendezvous and Proximity Operations. I'm Minduli Wijayatunga, a new assistant professor at UIUC, in Space Systems and Controls. This course is being constructed and run for the first time, so your feedback before, during and after it is incredibly valuable to me.

Overview

This course provides a comprehensive treatment of spacecraft rendezvous, proximity operations, and docking (RPO), with a primary emphasis on autonomous trajectory design and guidance, navigation, and control (GNC). Students develop a rigorous understanding of relative motion dynamics, rendezvous and proximity trajectory design, and closed-loop guidance and navigation under realistic constraints in sensing, actuation, and operational implementation. Classical impulsive and low-thrust rendezvous methods are integrated with contemporary optimization-based guidance and safety-critical constraint enforcement. The course also introduces enabling autonomy topics that increasingly shape modern RPO systems, including perception-driven proximity operations, reinforcement learning enabled guidance, control barrier functions and verification and validation of RPO.

Prerequisites

AE 402, AE 353 (or equivalent), AE 485 (optional), and familiarity with a programming language (Python, Matlab, etc.)

Web Page

Lecture Time and Location

xx PM - xx PM on Tuesdays and Thursdays, [Place], [Hybrid online info]

Instructor's Office Hours

TBD

Objectives

Upon completion of this course, a student will learn to:

- Model relative motion and design trajectory, guidance, navigation, and control for various RPO mission stages.
- Integrate operational requirements governed by perception and constraints that ensure safety to execute proximity operations robustly under uncertainty.
- Develop and justify an end-to-end RPO concept and verify performance via reproducible simulation and testing.

Topics

To various levels of detail, this course would cover:

- Overview of orbital mechanics and system dynamics and control
- Relative orbital motion modeling
- Mission design and requirements for different RPO stages
- Trajectory design methods for RPO, including impulsive and low thrust methods and safety considerations
- Perception and tools for relative navigation
- Theory of thruster configuration and allocation
- Applications of Convex Optimization, Model Predictive Control and Simple Adaptive Control in RPO
- Applications of learning methods in RPO
- Verification and validation of RPO technologies
- Applications of Control barrier functions and contraction theory in RPO

Course Format

This course will be taught primarily using slides to be posted on Canvas.

Recommended Textbooks

There are no required textbooks but some of the course topics are based on:

- *Automated Rendezvous and Docking of Spacecraft* by Wigbert Fehse

Assignments and Exams

There will be four take-home assignments distributed throughout the semester. There is no midterm or final exam; instead, students will complete an individual research project.

All students must adhere to the Honor Code (see below) for all assessments. Each student must submit their own work. Collaboration in a group setting is permitted, **provided it does not result in shared written solutions or copied code.**

The use of large language models (LLMs) to generate assignment answers is discouraged. However, students may use research-discovery tools (e.g., Google Scholar Labs and similar literature-search assistants) to identify relevant papers and resources for their final project.

Violations of the Honor Code or academic integrity policy may result in a failing grade for the assignment and/or the course.

Final Project

Each student must complete an individual final project as part of the course assessment. Students will select a topic of interest within spacecraft rendezvous and proximity operations (RPO). Project expectations and topic selection will be discussed in Week 1 and revisited again in Week 10.

Students are expected to make an original technical contribution through their final projects. Examples include: (i) reproducing a recently published (2021 or later) result and critically analyzing underlying assumptions; (ii) conducting a quantitative comparison of two or more RPO approaches (e.g., MPC versus RL for guidance); or (iii) adapting a method from a neighboring field (e.g., robotics or optimization) to an RPO application.

Students are encouraged to begin thinking about their final project from Week 1 and progressively refine their ideas as the course progresses.

In Week 4, students must submit a short (3–5 sentence) description of their proposed topic and motivation via Canvas. Students are encouraged to meet with the instructor between Weeks 10–12 to discuss scope and feasibility.

During the final week of instruction, students will deliver a short in-class project presentation summarizing their problem formulation, methodology, and preliminary or final results.

The final written project report is due during the university finals period and must be submitted in the format of an *AAS*-style paper.

Key Deadlines

Key Deadlines: Assignments and Assessments

Table 1: Assignment Deadlines

Item	**Week**	**Due**	**Coverage / notes**
Assignment 1	3	Fri Sep 11	Relative motion dynamics; reference frames; introductory rendezvous modelling.
Assignment 2	5	Fri Sep 25	Trajectory design for RPO; impulsive and low-thrust transfers; safety constraints and keep-out zones.
Assignment 3	7	Fri Oct 9	Relative navigation and perception; measurement models; estimation and filtering concepts.
Assignment 4	12	Fri Nov 13	Guidance and control design; phase-dependent guidance laws; thruster configuration and allocation.

Table 2: Project Deadlines

Milestone	**Due**	**Notes**
3–5 sentence project description	Week 4 (Fri Sep 18, 11.59 PM)	Graded (5%)
Instructor meetings	Weeks 10–12	Not graded
Proposal + literature review	Week 12 (Fri Nov 13, 11.59 PM)	Graded (10%)
Project presentations	Week 16	Graded (15%)
Final report (TAES-style paper)	Wed Dec 9th 11.59 PM	Graded (20%)

Grading

The grades will be weighted as follows:

- Assignments: 50%, Final Project: 50%

Anticipated Course Schedule

This is a newly established course so the schedule may vary significantly depending on the students' levels of understanding:

Week	Dates	Topic
1	Aug 24 – Aug 28	Course introduction & logistics; history and stages of RPO missions, review of orbital mechanics
2	Aug 31 – Sep 4	Relative Motion & Equations of Motion, Floquet Theorem
3	Sep 7 – Sep 11	Trajectory design I: impulsive (dual- and multi-impulse) versus low-thrust transfers; mission planning for different phases; constraints
4	Sep 14 – Sep 18	Trajectory design II: safety in RPO
5	Sep 21 – Sep 25	Navigation and perception: relative measurement systems; sensors; filtering methods; navigation architecture design
6	Sep 28 – Oct 2	GNC I: Lyapunov-based control; traditional guidance and control methods
7	Oct 5 – Oct 9	GNC II: control barrier functions (CBFs); advanced CBFs for RPO safety
8	Oct 12 – Oct 16	GNC III: convex optimization; applications of convex optimization in RPO
9	Oct 19 – Oct 23	Midterm review; final project check-in and discussion (topic selection, literature review methodology, proposal guidance)
10	Oct 26 – Oct 30	GNC IV:Model Predictive Control; applications of learning in RPO
11	Nov 2 – Nov 6	GNC V: Simple Adaptive Control (SAC) and nonlinear observers; contraction theory
12	Nov 9 – Nov 13	Advanced topics I: pursuit–evasion games; guest lecture: computer vision for RPO
13	Nov 16 – Nov 20	Advanced topics II: guest lecture: LLMs in RPO; guest lecture: experimental RPO
14	Nov 23 – Nov 27	Fall Break (no instruction)
15	Nov 30 – Dec 4	Edge of research: open research problems in autonomous RPO
16	Dec 7 – Dec 9	Presentations Week
17	Dec 11 – Dec 17	Nothing, you're all done!

Honor Code

The details can be found here:

- https://studentcode.illinois.edu/article1/part4/1-401/
- https://siebelschool.illinois.edu/academics/honor-code