

ELEC 4906: SATELLITE BASED INTEGRATED NAVIGATION

Introduction

Satellite-based integrated navigation systems have revolutionized modern navigation by combining the precision of Global Navigation Satellite Systems (GNSS) with the robustness of Inertial Navigation Systems (INS). These systems leverage GNSS principles, user positioning techniques, and differential methods to deliver accurate and reliable navigation solutions. With the integration of Kalman filtering, they achieve seamless operation by merging GNSS and INS data, providing a comprehensive approach to advanced navigation challenges.

Course Description and Requirements

This course begins with an introduction to navigation basics and reference frames, providing a strong foundation. It then delves into GNSS, focusing on the Global Positioning System (GPS), including its segments, observables, signals, and the computation of satellite position and velocity. The course further explores user positioning, differential techniques, and GPS receivers. It concludes with an introduction to Inertial Navigation Systems (INS), Kalman filtering, and the integration of INS/GPS in modes such as Loosely Coupled, Tightly Coupled, and Ultra-tightly Coupled, offering a comprehensive understanding of modern navigation systems.

Includes: Experiential learning activity

Prerequisite(s): Fourth-year status in Engineering

Lectures: Lectures three hours per week.

Laboratory: Laboratories three hours alternate week.

Instructor

Professor: Tashfeen Karamat

Email: tashfeen.karamat@carleton.ca

Course Webpage: on Brightspace

Office: 4526 EDC

Course material

Lecture Notes

Lecture notes will be provided as pdf.

Textbook

- Noureldin A., Karamat T. and Georgy J.: "Fundamentals of Inertial Navigation, Satellite-based Positioning and their Integration" Springer, ISBN 978-3-642-30465-1, October 2012.
 - Hardcover: C\$244.10, Paperback: C\$167.46, Kindle: C\$159.85

Reference Books

- Frank van Diggelen: “A-GPS: Assisted GPS, GNSS, and SBAS” Artech House; 1st edition, March 31, 2009
 - Hardcover: C\$245.79, Paperback: 440.13
- Pratap Misra, Per Enge: Global Positioning System: Signals, Measurements, and Performance, Ganga-Jamuna Press 2010.
 - Paperback: C\$117

Software

The software used for the course is called ‘gLAB’ which is developed under a European Space Agency (ESA) Contract by the research group of Astronomy and Geomatics (gAGE) from the Universitat Politècnica de Catalunya (UPC). It is an interactive educational multipurpose package to process and analyse GNSS data.

Lecture Outline

Lectures will be “In-person”. Course information, lectures, grades and other relevant material will be posted on the ELEC 4906 Brightspace site. Students are expected to regularly check the Brightspace site for course handouts, lecture notes and course announcements.

The following is a breakdown of the topics that will be covered each week. There may be a slight variation in their order to adjust for any unforeseen circumstances:

Week 1: Introduction to navigation including INS, GPS, and their integration

Week 2: Coordinate Frames

Week 3: GPS Segments, GPS Observables & Errors

Week 4: GPS Signals

Week 5: GPS Orbits, Satellite Position & Velocity

Week 6: Receiver Position & Velocity, Differential GNSS (DGNSS)

Week 7: Precise Point Positioning (PPP), Receiver Basics

Week 8: Front-end & Mixers, Receiver Architecture

Week 9: Signal Acquisition & Search Space, Assisted GPS (AGPS)

Week 10: Inertial Navigation System

Week 11: INS Errors & Sensor Calibration

Week 12: Kalman Filtering (KF) & Integrated Navigation

Laboratory

There will be 5 labs as per schedule and location posted on Brightspace. All labs will use actual GPS data to demonstrate various practical aspects of GPS. Lab attendance is a mandatory requirement of the course.

Labs

There are 5 labs as follows:

- Lab 1: GPS Data Formats & Processing
- Lab 2: GPS Data Processing for Standard Point Positioning (SPP)
- Lab 3: Model Component Analysis for SPP
- Lab 4: GPS Data Processing for Precise Point Positioning (PPP)
- Lab 5: Model Component Analysis for PPP
- Lab 6: GPS Data Processing for Differential GPS (DGPS)

Lab Reports

- The lab reports will be evaluated to ensure students performed and understood the experiment as required and recorded or calculated all necessary values.
- A single Lab Report per student is to be submitted online using the relevant Lab page on Brightspace before the deadline.
- Students will prepare the lab reports during the lab as they progress through the lab while analyse the data. Therefore, the Lab reports are due at the end of the lab.
- Lab reports submitted after the end of the labs will get no marks for the lab.

Final Exam

- The final exam will evaluate student understanding of all course concepts. As soon as the date of the final exam is confirmed by Scheduling and Examination Services (SES) it will be communicated to you by SES, and you can find it on "<https://carleton.ca/ses/exam-schedule>". Final exam will take place outside of class time (which can include Friday evening, Saturday, or Sunday).
- The final examination is for evaluation purposes only and will not be returned to students. You will be able to make arrangements with the instructor or with the department office to see your marked final examination after the final grades have been made available. This should be done no later than 3 days after the marks are posted.
- The exam will be Closed-Book and Closed-Notes and no reference materials are allowed.
- You can bring your handwritten notes to the final exam.
- No electronic device except for non-graphing and non-programmable calculators is permitted in the final exam.

Exam format and proctoring statement

The final exam will be proctored and administered on campus. The exam will be paper-based, and answers will need to be written/indicated on Scantron sheets.

Deferred Final Examinations

Students who are unable to write the final examination because of a serious illness/emergency or other circumstances beyond their control may apply for accommodation by contact the Registrar's office. Consult the Section 4.3 of the University Calendar

(<https://calendar.carleton.ca/undergrad/regulations/academicregulationsoftheuniversity/examinations/>)

Evaluation and Grading Scheme

The cumulative course grade will be determined as follows:

Component	Weight
Labs	15%
Midterm 1	15%
Midterm 2	15%
Final Exam	55%

- To pass the course, students must achieve satisfactory performance during the term as well as in the final exam.
- Satisfactory performance during the term is completion of the lab experiments with a combined average grade of $\geq 50\%$.
- Students who fail the final exam (an exam grade of less than 50%) will receive a course grade of F, regardless of their marks in the other components. For students who pass the final exam, a numeric mark out of 100 will be calculated by weighing the course components as shown in the table above.

Learning Outcomes

By the end of this course, students should:

- Be familiar with concepts of Navigation and basics and reference frames.
- Learn the fundamentals of Global Navigation Satellite Systems (GNSS) and specifics of Global Positioning System (GPS)
- Know the details of GPS Segments and Observables
- Be able compute position & velocity of the satellite from the orbital data (ephemeris)
- Be able to compute user position and velocity from the raw data (pseudorange and Doppler)
- Learn the concepts of Differential Positioning and Precise Point Positioning.
- Be able to know key concepts of GNSS Receiver.
- Know the fundamental concepts of Inertial Navigation Systems (INS)
- Learn the basics of Kalman filtering (KF) and its use in Navigation
- Learn the basics of various modes of GPS and INS Integration using Kalman filter

Self-Declaration form and Deferred Term work

Students who claim illness, injury or other extraordinary circumstances beyond their control as a reason for missed term work are held responsible for immediately informing the instructor concerned and for submitting a self-declaration form no later than three (3) days after the date/deadline of term work including test/midterm, labs, assignments. Any alternate arrangements made with the instructor for submission of term work should be made as soon as possible but within 3 days of the missed due date. If this is not possible after discussion with the instructor, alternate arrangements must be made before the last day of classes in the term as published in the academic schedule.

Consult with the instructor no later than 3 days after any missed course work or midterm examination.

Academic Integrity and Plagiarism

a) Please consult the Faculty of Engineering and Design information page about the Academic Integrity policy and our procedures: <https://carleton.ca/engineering-design/current-students/fed-academic-integrity>. Violations of the Academic Integrity Policy will result in the assignment of a penalty such as reduced grades, the assignment of an F in a course, a suspension or expulsion.

b) One of the main objectives of the Academic Integrity Policy is to ensure that the work you submit is your own. As a result, it is important to write your own solutions when studying and preparing with other students and to avoid plagiarism in your submissions. The University Academic Integrity Policy defines plagiarism as “presenting, whether intentionally or not, the ideas, expression of ideas or work of others as one’s own.” This includes reproducing or paraphrasing portions of someone else’s published or unpublished material, regardless of the source, and presenting these as one’s own without proper citation or reference to the original source.

Examples of violations of the policy include, but are not limited to:

- Any submission prepared in whole or in part, by someone else.

- Using another’s data or research findings without appropriate acknowledgment.
- Submitting a computer program developed in whole or in part by someone else, with or without modifications, as one’s own.
- Failing to acknowledge sources of information through the use of proper citations when using another’s work and/or failing to use quotations marks; and
- Unless explicitly permitted by the instructor in a specific course, the use of generative AI and similar tools to produce assessed content (such as text, code, equations, images, summaries, videos, etc.).

Academic Accommodations

You may need special arrangements to meet your academic obligations during the term. For an accommodation request the processes are as follows:

Pregnancy obligation

Contact us with any requests for academic accommodation during the first two weeks of class, or as soon as possible after the need for accommodation is known to exist. For accommodation regarding a formally-scheduled final exam, you must complete the Pregnancy Accommodation Form ([click here](#)).

Religious obligation

Contact us with any requests for academic accommodation during the first two weeks of class, or as soon as possible after the need for accommodation is known to exist. For more details [click here](#).

Academic Accommodations for Students with Disabilities

The Paul Menton Centre for Students with Disabilities (PMC) provides services to students with Learning Disabilities (LD), psychiatric/mental health disabilities, Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorders (ASD), chronic medical conditions, and impairments in mobility, hearing, and vision. If you have a disability requiring academic accommodations in this course, please contact PMC at 613-520-6608 or pmc@carleton.ca for a formal evaluation. If you are already registered with the PMC, contact your PMC coordinator to send us your Letter of Accommodation at the beginning of the term, and no later than two weeks before the first in-class scheduled test or exam requiring accommodation (if applicable). After requesting accommodation from PMC, contact us, if needed, to ensure that accommodation arrangements are made.

You should request your academic accommodations in the [Ventus Student Portal](#), for each course at the beginning of every term. For in-term tests or midterms, please request accommodation at least two (2) weeks before the first test or midterm.

Please consult the [PMC website](#) for the deadline to request accommodations for formally-scheduled exams (if applicable).

Survivors of Sexual Violence

As a community, Carleton University is committed to maintaining a positive learning, working and living environment where sexual violence will not be tolerated, and where survivors are supported through academic accommodations as per Carleton’s Sexual Violence Policy. For more information about the services available at the university and to obtain information about sexual violence and/or support, visit:

<https://carleton.ca/equity/sexual-assault-support-services>

Accommodation for Student Activities

Carleton University recognizes the substantial benefits, both to the individual student and for the university, which result from a student participating in activities beyond the classroom experience. Reasonable

accommodation will be provided to students who compete or perform at the national or international level. Contact us with any requests for academic accommodation during the first two weeks of class, or as soon as possible after the need for accommodation is known to exist: <https://carleton.ca/senate/wp-content/uploads/Accommodation-for-Student-Activities-1.pdf>

Advising and Counselling services

Engineering Academic Advising

The Engineering Academic Support Service : <https://carleton.ca/engineering-design/current-students/undergrad-academic-support/> assists undergraduate engineering students with course selection, registration, and learning support from first-year through to graduation.

Academic Advisors Contact : <https://carleton.ca/engineering-design/current-students/undergrad-academic-support/undergraduate-advisors/>

Student Mental Health Service

As a university student you may experience a range of mental health challenges that significantly impact your academic success and overall well-being. Carleton's Wellness Services Navigator <https://wellness.carleton.ca/navigator/> is designed to help students connect with mental health and wellness resources. If you need to talk to someone, please reach out for assistance: <https://carleton.ca/health/emergencies-and-crisis/>.

Learning and Working Environment

The University and all members of the University community share responsibility for ensuring that the University's educational, work and living environments are free from discrimination and harassment. Should you have concerns about harassment or discrimination relating to your age, ancestry, citizenship, colour, creed (religion), disability, ethnic origin, family status, gender expression, gender identity, marital status, place of origin, race, sex (including pregnancy), or sexual orientation, please contact the Department of Equity and Inclusive Communities at equity@carleton.ca

We will strive to create an environment of mutual respect for all through equity, diversity, and inclusion within this course. The space which we work in will be safe for everyone. Please be considerate of everyone's personal beliefs, choices, and opinions.

General Regulations

Attendance

Students are expected to attend all lectures and lab periods In-Person. Lab attendance is a mandatory requirement of the course. The University requires students to have a conflict-free timetable. For more information, see the current *Undergraduate Calendar, Academic Regulations of the University, Section 1.2, Course Selection and Registration and Section 1.5, Deregistration*.

Health and Safety

Every student should have a copy of our Health and Safety Manual. A PDF copy of this manual is available online: <http://sce.carleton.ca/courses/health-and-safety.pdf>

Appeal of Grades

The processes for dealing with questions or concerns regarding grades assigned during the term and final grades is described in the *Undergraduate Calendar, Academic Regulations of the University, Section 2.7, Informal Appeal of Grade and Section 2.8, Formal Appeal of Grade*.

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