CAP6419: 3D Computer Vision

Department of Computer Science, CECS
Credit Hours: 3

Course Syllabus

Instructor:	Dr. Hassan Foroosh	Term:	Fall 2024
Office Location:	HEC 212	Class Meeting Days:	Tue/Thu
Office Hours:	Tue: 1:45 – as needed Other times scheduled upon request	Class Meeting Time:	4:30-5:45
Phone:	407-823-5299	Class Location:	BA1-216A
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GTA(s):	N/A	Email:	N/A

Course Description

Official course description: 2D/3D Projective Geometry, Projective Transformation Estimation, Camera Calibration, Single View Modeling, Bi-focal Modeling, Fundamental Matrix, Stratified Structure, Homography, Tri-focal Tensor, Auto-Calibration, Chirality.

Course Rationale: Understanding the 3D world from 2D images is a central problem in computer vision that has a wide range of applications in intelligent and autonomous systems, such as self-driving or assistive cars, robotics, virtual and augmented reality, simulation and training, movie and game industry, smart homes, human-computer interaction, and literally any application area that requires machine interpretation and understanding of images and videos. Research in the general area of computer vision has gone through a fascinating transformation over the past few decades. In the niche area of 3D computer vision, many fundamental concepts and theoretical underpinnings are now well-understood and accessible for a stand-alone course to be offered in this area, with several textbooks available to provide the supporting material. On the other hand, gaining a deep understanding of such fundamental concepts builds the backbone of any pioneering research, whether in academia or industry, in any of the application areas highlighted above. This course provides those crucial building blocks and enables students to develop both theoretical and practical skills to conduct state-of-the-art research in this area.

Course Goals:

1. Learn the fundamentals of projective geometry in 2D and 3D, and gain in-depth understanding of their role in modeling the geometry of the 3D world from images.

2. Understand the geometric transformations in 2D and 3D, and learn the importance of the associated invariants.
3. Learn the mathematical models of a camera and understand the relationship between such models and the geometry of the 3D world captured in images.
4. Gain practical skills of applying the theories and acquire hands-on experience with 3D computer vision techniques using a high-level programming language such as Matlab.

Major Topics Covered in the Course:

1. 2D Projective Geometry: projective plane, hierarchy of transformations, invariants, planar rectifications
2. 3D Projective Geometry: Principles, hierarchy of transformations, significance of ideal points, absolute conic, absolute dual quadric
3. Estimation of projective transformation
4. Evaluation of algorithmic errors
5. Mathematical model of Camera
6. Camera calibration
7. Single view modeling: recovering 3D scene structure from a single view, recovering camera position and pose
8. Stereovision: epipolar geometry, fundamental matrix, recovering 3D scene structure from two views
9. Stratified Structure
10. Scene planes and homographies
11. Multilinearity
12. Camera auto-Calibration
13. Chirality
14. Degenerate configurations

Course Learning Outcomes and Expected Performance Criteria

1. A passing student shall be familiar with fundamentals of 2D and 3D projective geometry and the associated linear algebra.
2. A passing student shall be familiar with basic linear and non-linear estimation techniques and computation of uncertainties. Students should be able to develop code for these estimation methods.
3. A passing student shall understand the constraints imposed by geometric characteristics such as collinearity and coplanarity, including geometry of points, lines, and conics at infinity.
4. A passing student shall understand the mathematical model of a pin hole camera.
5. A passing student shall understand camera calibration methods and be able to implement various calibration techniques in a high-level language.
6. A passing student shall understand geometric constraints associated with a single view, and the 3D reconstruction techniques from a single image.
7. A passing student shall understand epipolar geometry and the basic principles of stereo vision, including the computation of the fundamental matrix and the essential matrix.
8. A passing student shall understand geometric constraints associated with a two or more views, and the 3D reconstruction techniques from multiple images.
9. A passing student shall understand and be able to implement the basic techniques of auto-calibration.
10. A passing student shall understand the degenerate cases in camera calibration, camera pose estimation, and 3D reconstruction from images.

Enrollment Requirements

Prerequisites: CAP 5415 or EEL 5820 or Consent of the instructor

Course Activities

The following table provides a tentative sequence of course activities:

Schedule	Module	Description
Week 1, Day 1	Lecture 1	Introduction
Week 1	Roll Call Assignment	A paragraph to be submitted: Students introducing themselves, their background and research interest
Week 1, Day 2	Lecture 2	Background
Week 2	Assignment 1	Fundamental Concepts in Projective geometry
Week 2, Day 1	Lecture 3	2D Projective Geometry
Week 2, Day 2	Lecture 4	2D Projective Geometry (Cont.)
Week 3, Day 1	Lecture 5	Line at infinity and circular points
Week 3	Assignment 2	Combined theory and programming assignment: 2D Projective/Affine/Euclidean rectification
Week 3, Day 2	Lecture 6	3D Projective Geometry
Week 4, Day 1	Lecture 7	3D Projective Geometry (Cont.)
Week 4, Day 2	Lecture 8	Hierarchy of geometric Transformations
Week 5, Day 1	Lecture 9	Plane at Infinity
Week 5	Assignment 3	Programming project: 3D Projective/Affine/Euclidean rectification
Week 5, Day 2	Lecture 10	Geometric invariants
Week 6, Day 1	Lecture 11	Estimation methods
Week 6, Day 2	Lecture 12	Error analysis and error propagation in algorithms
Week 7, Day 1	Lecture 13	Pinhole Camera Model
Week 7, Day 2	Lecture 14	Camera motions and special cases: Application
Week 7	Assignment 4	Programming project: Panoramic view generation
Week 8, Day 1	Lecture 15	Genera camera motion: extrinsic parameters
Week 8, Day 2	Lecture 16	Camera calibration
Week 9, Day 1	Lecture 17	Classical calibration methods
Week 9, Day 2	Lecture 18	Absolute conic and Image of the Absolute Conic (IAC)
Week 10, Day 1	Lecture 19	Role of IAC in 3D computer vision
Week 10	Assignment 5	Programming project: Single view metrology
Week 10, Day 2	Lecture 20	Epipolar geometry
Week 11, Day 1	Lecture 21	Stereo vision
Week 11, Day 2	Lecture 22	Stratification of structure
Week 11	Assignment 6	Programming project:

		Stereo reconstruction by exploiting symmetry
Week 12, Day 1	Lecture 23	Camera pose estimation
Week 12, Day 2	Lecture 24	General structure from motion
Week 12	Final Project	Based on a recently published paper in the area. Due at the end of exam week
Week 13, Day 1	Lecture 25	Planes and their role in 3D scene
Week 13, Day 2	Lecture 26	Introduction to Autocalibration
Week 14, Day 1	Lecture 27	Kruppa Equations
Week 14, Day 2	Lecture 28	Absolute quadric and its application in autocalibration
Week 15, Day 1	Lecture 29	Chirality and degeneracy
Week 15, Day 2	Lecture 30	A survey of applications
Week 16	Final Project Due	Exam week

Assessment and Grading Procedures

Roll call assignment: 2% (extra credit)

Homework assignments = 40% total equally distributed

Programming projects including the final project = 60% total equally distributed

All assignments are to be performed individually.

Grading breakdown ranges:

90% - 100%: A

80% - 90%: B

70% - 80%: C

Less than 70%: D

Plus/minus scales are used for the upper half and the lower half of each range.

Make-up Exams and Assignments

See the section on Course Policies below.

Grade Dissemination

All graded assignments and projects will be disseminated via webcourses.

Course Materials and Resources

Recommended Textbook: Multiple View Geometry in Computer Vision, Richard Hartley and Andrew Zisserman, Cambridge University Press, 2nd Edition, 2000-2003, ISBN 0-521-54051-8

All other materials, including lecture notes and supplementary videos will be made available on the course web site via webcourses.

Course Policies

Academic Integrity

Students should familiarize themselves with UCF's Rules of Conduct at: https://scai.sdes.ucf.edu/student-rules-of-conduct/. According to Section 1, "Academic Misconduct," students are prohibited from engaging in

1. Unauthorized assistance: Using or attempting to use unauthorized materials, information or study aids in any academic exercise unless specifically authorized by the instructor of record. The unauthorized possession of examination or course-related material also constitutes cheating.
2. Communication to another through written, visual, electronic, or oral means: The presentation of material which has not been studied or learned, but rather was obtained through someone else's efforts and used as part of an examination, course assignment, or project.
3. Commercial Use of Academic Material: Selling of course material to another person, student, and/or uploading course material to a third-party vendor without authorization or without the express written permission of the university and the instructor. Course materials include but are not limited to class notes, Instructor's PowerPoints, course syllabi, tests, quizzes, labs, instruction sheets, homework, study guides, handouts, etc.
4. Falsifying or misrepresenting the student's own academic work.
5. Plagiarism: Using or appropriating another's work without any indication of the source, thereby attempting to convey the impression that such work is the student's own.
6. Multiple Submissions: Submitting the same academic work for credit more than once without the express written permission of the instructor.
7. Helping another violate academic behavior standards.
8. Soliciting assistance with academic coursework and/or degree requirements.

Responses to Academic Dishonesty, Plagiarism, or Cheating: Students should familiarize themselves with the procedures for academic misconduct in UCF's student handbook, *The Golden Rule* <https://goldenrule.sdes.ucf.edu/>. UCF faculty members have a responsibility for students' education and the value of a UCF degree, and so seek to prevent unethical behavior and respond to academic misconduct when necessary. Penalties for violating rules, policies, and instructions within this course can range from a zero on the exercise to an "F" letter grade in the course. In addition, an Academic Misconduct report could be filed with the Office of Student Conduct, which could lead to disciplinary warning, disciplinary probation, or deferred suspension or separation from the University through suspension, dismissal, or expulsion with the addition of a "Z" designation on one's transcript.
Being found in violation of academic conduct standards could result in a student having to disclose such behavior on a graduate school application, being removed from a leadership position within a student organization, the recipient of scholarships, participation in University activities such as study abroad, internships, etc.

Let's avoid all of this by demonstrating values of honesty, trust, and integrity. No grade is worth compromising your integrity and moving your moral compass. Stay true to doing the right thing: take the zero, not a shortcut.

Accessibility

The University of Central Florida is committed to providing access and inclusion for all persons with disabilities. Students with disabilities who need access to course content due to course design limitations should contact the professor as soon as possible. Students should also connect with Student Accessibility Services (SAS) <http://sas.sdes.ucf.edu/> (Ferrell Commons 185, sas@ucf.edu, phone 407-823-2371). For students connected with SAS, a Course Accessibility Letter may be created and sent to professors, which informs faculty of potential course access and accommodations that might be necessary and reasonable. Determining reasonable access and accommodations requires consideration of the course design, course learning objectives and the individual academic and course barriers experienced by the student. Further conversation with SAS, faculty and the student may be warranted to ensure an accessible course experience.

Safety

Although most emergency situations are primarily relevant to courses that meet in person, such incidents can also impact online students, either when they are on or near campus to participate in other courses or activities or when their course work is affected by off-campus emergencies. At UCF, the following policies apply to courses in online modalities.

- To stay informed about emergency situations, students can sign up to receive UCF text alerts by going to <https://my.ucf.edu> and logging in. Click on “Student Self Service” located on the left side of the screen in the toolbar, scroll down to the blue “Personal Information” heading on the Student Center screen, click on “UCF Alert”, fill out the information, including e-mail address, cell phone number, and cell phone provider, click “Apply” to save the changes, and then click “OK.”
- Students with special needs related to emergency situations should speak with their instructors outside of class.

Active Duty

Students who are deployed active-duty military and/or National Guard personnel and require accommodation should contact the instructor as soon as possible after the semester begins and/or after they receive notification of deployment to make related arrangements.

Make-Up Assignments for Authorized University Events or Co-curricular Activities

Students who represent the university in an authorized event or activity (for example, student-athletes) and who are unable to meet a course deadline due to a conflict with that event must provide documentation in advance to arrange a make-up or extended time. No penalty will be applied. For more information, see the UCF policy at <https://policies.ucf.edu/documents/4-401.pdf>

In-Class Recording

Students may, without prior notice, record video or audio of a class lecture for a class in which the student is enrolled for their own personal educational use. A class lecture is defined as a formal or methodical oral presentation as part of a university course intended to present information or teach enrolled students about a particular subject. Recording class activities other than class lectures, including but not limited to lab sessions, student presentations (whether individually or part of a group), class discussion (except when incidental to and incorporated within a class lecture), clinical presentations such as patient history, academic exercises involving student participation, test or examination administrations, field trips, private conversations between students in the class or between a student and the faculty member, and invited guest speakers is prohibited. Recordings may not be used as a substitute for class participation and class attendance, and may not be published or shared without the written consent of the faculty member. Failure to adhere to these requirements may constitute a violation of the University's Student Code of Conduct as described in the Golden Rule.