EE292Q: 3D+ Imaging Sensors

Department of Electrical Engineering
Stanford University

General Information

Lectures: Tue, 5:30 – 7:30 PM at 300-303.
Units: 3
Prerequisites: EE 101A, EE 102A.
Websites:
Course Website on Canvas: https://canvas.stanford.edu/courses/156159
Discussion Forum on Piazza: https://piazza.com/stanford/spring2022/ee292q

Course Description

This course provides an introduction to operation principles and key performance aspects of 3D+ imaging sensors used widely in industry. Unlike conventional imaging courses, the content is not limited to a specific sensor modality, instead, the lectures broadly cover technical terms related to any multidimensional imaging sensor. Concepts covered include imaging physics, data acquisition and image formation methods, and signal and image quality metrics. For advanced sensors, like imaging radars, higher dimensional image content (3D+) will be therefore easier to comprehend and interpret.

Practical examples and demonstrations of various sensors such as radar, acoustic, LIDAR, and ToF modules will be presented in class as well as through structured lab-based components for hands-on learning. Invited speakers will highlight emerging 3D+ imaging applications that these sensors are enabling today.

Instructors

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Office Hours

To be Finalized

Administrator

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References:

a) "Principles of Optics" by Max Born and Emil Wolf
b) "A Source Book in Greek Science" by Morris R. Cohen and I. E. Drabkin
c) "Signals and Systems" by Alan Oppenheim
d) "The Scientist & Engineer's Guide to Digital Signal Processing" by Steven W. Smith
e) "Optical Imaging and Photography: Introduction to Science and Technology of Optics, Sensors and Systems" by Ulrich Teubner and Hans Josef Brückner
f) "Introduction to Sensors for Ranging and Imaging" by Graham Brooker
g) "LiDAR Technologies and Systems" by Paul F. McManamon
h) "Seeing: The Computational Approach to Biological Vision" by John Frisby and James Stone
i) "Ultrasound Imaging and Therapy" by Aaron Fenster and James Lacefield
j) "Introduction to Synthetic Aperture Radar: Concepts and Practice" by E. David Jansing

Texts are recommended but not required.

Grading

1. Homework – 30%
2. Lab reports – 35%
3. Final Exam – 35%

Piazza

Piazza will be a valuable open forum for students to interact among themselves and discuss questions/course content. Instructors will also monitor Piazza and provide clarification/help where needed. Occasionally, we will be using Piazza to post clarifications on assignments, though most announcements will be made via Canvas. Note that answers containing complete solutions to the homework problems are not allowed and will be modified by the TAs. To facilitate student interaction**, extra credit** will be given to the students with the highest participation in answering questions (correct answers will be endorsed by instructors). For such content-related questions, therefore, instructors will first wait for any student responses before providing help themselves.

Honor Code

We encourage students to collaborate on assignments. However, each student must write down the solutions independently. In other words, each student must understand the solution well enough in order to reconstruct it by him/herself; students may not look at each other's solutions. In addition, please do not treat Piazza as a way of "checking" answers to homework questions, as we expect everyone to abide by Stanford's honor code. Just as a reminder, the honor code applies to all parts of all classes; more information can be found at:
https://communitystandards.stanford.edu/student-conduct-process/honor-code-and-fundamental-standard#honor-code

Students with Documented Disabilities

Students who may need an academic accommodation based on the impact of a disability must initiate the request with the Office of Accessible Education (OAE). Professional staff will evaluate the request with required documentation, recommend reasonable accommodations, and prepare an Accommodation Letter for faculty. Unless the student has a temporary disability, Accommodation letters are issued for the entire academic year. Students should contact the OAE as soon as possible since timely notice is needed to coordinate accommodations. The OAE is located at 563 Salvatierra Walk (phone: 723-1066, URL: https://oae.stanford.edu/).

Homework and Lab Scheduling and Submission

Homeworks and labs will be conducted on alternative weeks – such that students only have one deliverable to be submitted each week. There are 3 mandatory homeworks and 3 mandatory lab sessions that every student must complete.

Homework will be handed out on Tuesday. Homeworks will be due the following Tuesday at 12:00pm (NOON), unless otherwise stated. All students should submit their homework electronically through Canvas. Please make sure your homework is legible after scanning or photographing. Do not email your homework to the teaching staff.

Students will work in groups of 3 for the labs – with lab times and lab groups finalized in the first week of class. Lab write-ups (as a group) will be due on Tuesday at 12:00pm (NOON) in the week following the corresponding lab session, unless otherwise stated. All groups should submit their lab write-up electronically through Canvas. Please make sure your lab write-up is written in a word processor or LaTeX, no handwritten submissions will be accepted. Do not email your lab write-up to the teaching staff.

Regrading Policy

1. If you request a regrade of your assignment, the whole assignment will be regraded.
2. Regrade request must be submitted within a week from when the grades are released.

Best Practices for Learning in this Course

1. Download slides beforehand and take careful notes during lecture.
2. Ask immediately if something is not clear to you during lecture.
3. Participate actively on Piazza; do think critically before posting a question.
4. Always review after each lecture; every slide exists for an important reason so do know the importance of each slide; derivations are important to carry out on your own.

Course Information

This course is structured such that each lecture focuses on specific technical areas while maintaining a generic scope to accommodate various 3D+ sensor modalities.

A summary of each lecture's targets and scope is provided below:

> **Lecture 1) Introduction to Imaging:** The opening lecture introduces students to the course content as well as a broader overview of the evolution of imaging over time. Students will learn about the generic handling of the imaging methods rather than the conventional digital imagery they know in their daily life. The lecture then progresses towards the definition of terms related to image representations, provides brief examples for three-dimensional imaging and beyond.

Lecture 2) Signal Quality: This lecture analyzes the major quality metrics associated with acquired sensor data such as noise, SNR, dynamic range, signal non-linearities among others. Students will understand the nonidealities associated with captured sensor data and how this might impact their judgment in utilizing the sensed information.

Lecture 3) Data Acquisition: This lecture establishes the foundations for the students to understand data acquisition methods when electronic sensors are utilized. They will learn about the main challenges involved and the common techniques employed to tackle them. This will prepare the students to confidently read and understand product datasheets or technical descriptions of any sensor. Exemplary material of datasheet sections will be used for illustration too.

Lab 1) The first lab will use acoustic and Time-of-Flight (ToF) modules to demonstrate concepts taught until now. Examples include basic experiments related to target ranging, attenuation, and material effects to highlight the unique capabilities of each sensor.

Lecture 4) Image Formation: Progressing from individual signals to an actual multidimensional image, related technical terms and techniques will be presented and explained. Unlike communication systems, where signals can be consumed directly, in imaging systems extra processing is essential to acquire a meaningful image.

Lecture 5) Image Quality: Based on preceding lectures, students are now ready to witness the impact of the taught technical parameters on the actual acquired image. The image itself is also subject to various quality metrics that get influenced by the parameters related to the data acquisition, signal quality, and image formation. Accordingly, the students will achieve understanding in how to close the loop between the system parameters and the final image outcome.

Lab 2) The second lab will build on the previous one to expose students to more complex acoustic and ToF imaging principles. Experiments will demonstrate the signal quality and data acquisition process as well as analyze achievable image quality using these sensing modalities.

Lecture 6) Imaging Radars: This lecture focuses specifically on the technical operation and capabilities of multidimensional radar systems. Imaging radars are the most advanced real-time capable 3D+ sensors nowadays and therefore provide a good example for learning. Due the associated complexity of radars, this lecture shall also facilitate the upcoming lab work scheduled for the week after.

Lectures 7) and 8) Imaging Applications: During those two weeks, lectures will be delivered on the modern applications of 3D+ sensors and challenges involved in real world deployment. This should equip the students with the practical knowledge of specific sensor types, and also help them see how theory and practice relate.

Lab 3) The third lab will introduce students to a mm-wave radar module. Experiments will demonstrate 3D and 3D+ (doppler) images captured by the radar and its functionality and tuning knobs.

Tentative Course Schedule:

Week #	Lecture and Lab	Assignments
Week 1 3/29	Lecture 1 - Introduction to Imaging	
Week 2 4/5	Lecture 2 - Signal Quality	Lab Safety Training
Week 3 4/12	Lecture 3 - Data Acquisition Methods Lab 1 - Acoustic and ToF Basics	HW1 out
Week 4 4/19	Lecture 4 - Image Formation	HW1 due Lab1 out
Week 5 4/26	Lecture 5 - Image Quality Lab 2 - Acoustic and ToF Advanced	HW2 out Lab1 due
Week 6 5/3	Lecture 6 - Imaging Radars	HW2 due Lab2 out
Week 7 5/10	Lecture 7 - Imaging Applications 1 Lab 3 – mm-wave Radar	HW3 out Lab2 due
Week 8 5/17	Lecture 8 - Imaging Applications 2	HW3 due Lab3 out
Week 9 5/24	Office hours & QA	Lab3 due
Week 10 5/31	**FINAL EXAM**	