Course Syllabus

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Civil and Environmental Engineering
University of Waterloo, Canada

CIVE 497 – CIVE 700: Smart Structure Technology

UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING

Last updated: 2024-01-08

Introduction – Chul Min Yeum

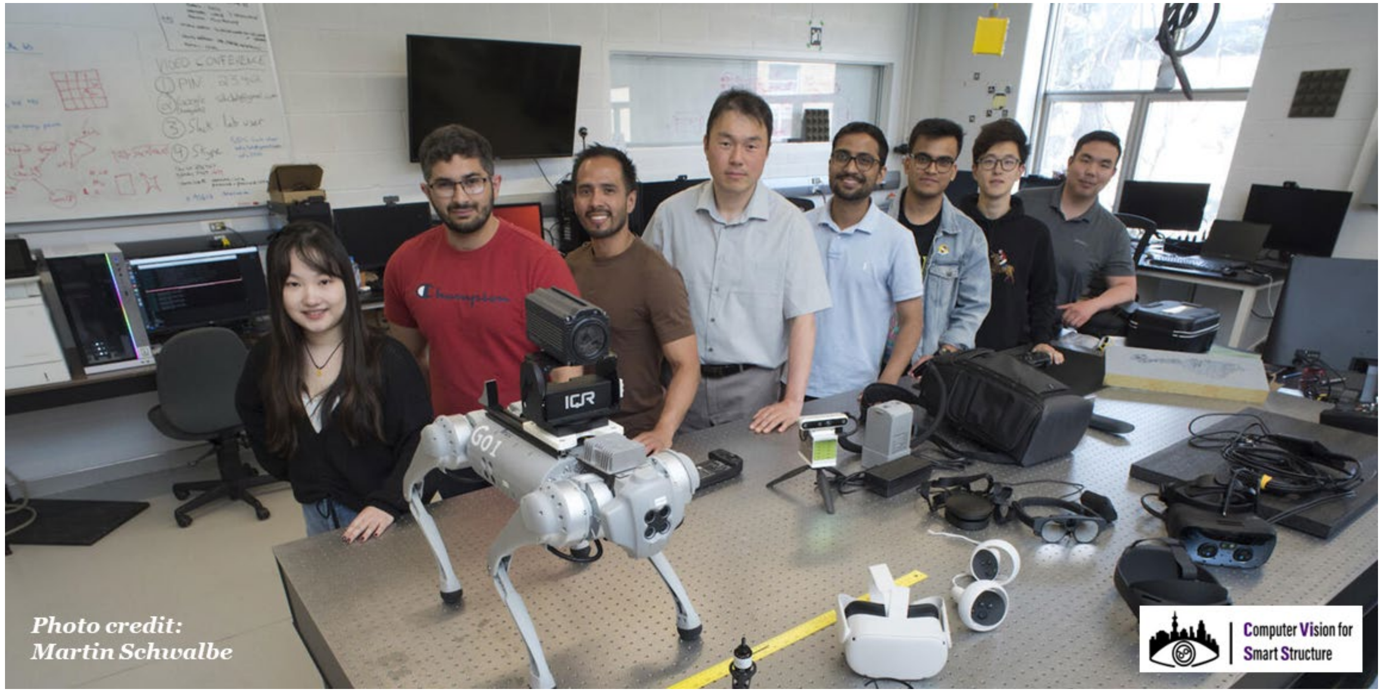
2018 — **Assistant Professor**
Civil Engineering
University of Waterloo, Canada

2016-2018 — **Postdoctoral Research**
Civil Engineering
Purdue University, United States

2012-2016 — **Doctoral Degree**
Civil Engineering
Purdue University, United States

2008-2010 — **Master's Degree**
Civil Engineering
Korea Advanced Institute of Science and Technology, South Korea

2002-2008 — **Bachelor's Degree**
Civil Engineering
Korea Advanced Institute of Science and Technology, South Korea



https://cviss.net

Course Description

This course offers an introduction to the emerging smart structure technologies in civil engineering. Smart structures integrate sensing, actuation, data processing, analysis, and visualization, and control capabilities so that a structure can sense and respond to its changing external conditions in a rapid and automated manner. Among several topics in smart structure, this course focuses on structural assessment **using optical sensor data** by implementing state-of-art image processing and computer vision techniques. As a special topic, basic concepts in **structure from motion**, **machine learning**, **neural networks**, and **neural radiance fields (NeRF)** are covered and relevant applications in civil engineering are introduced. An application-based learning approach is emphasized, and tasks are designed in such a way that students can implement smart structure technology to address contemporary problems in civil engineering.

Course Description (Continue)

This course is specially designed to suit the interest of **graduate students** and **senior undergraduate students who may pursue graduate studies**. You can see the course outline and task assignments in the previous year from **w2021**, **w2020**, **w2019**. Note that all lectures were already delivered through **pre-recorded videos** in 2021. When you are absent from a class, you can watch the corresponding lecture video. However, students are highly encouraged to attend the classes.

Based on past course surveys, students should anticipate dedicating **at least 20 hours per week** to study class materials, work on assignments, and undertake research projects. Additionally, a strong background in computer programming is expected of students. **If you are unsure about allocating this much time, please carefully reconsider enrolling.** For undergraduates, be aware that the instructor will not accommodate personal situations, like capstone projects, quizzes, midterms, or finals, that do not adhere to institutional policies and guidelines.

If You Haven’t Decide Whether You Take This Course or Not…

- If you're a graduate student with an interest in this field, I strongly recommend enrolling in this course. **It could offer fresh insights and perspectives that might be beneficial for your research.**

- For undergraduate students eager to take this course, you should meet at least one of the following criteria:
  - You should have a strong interest in programming and possess an **adequate level of computer programming skills.**
  - You should have completed at least one course, either from another department or through online platforms like Coursera, focusing on topics such as signal processing, image processing, computer vision, or machine learning.
  - This course would be beneficial if you're planning to pursue graduate studies in the future.
  - You should be able to dedicate more than 12 hours per week and be prepared for the challenges of an intensive course.

Course Objectives

By the end of this course, students should be able to

- Describe smart structure technology and its applications in civil engineering
- Explain the working principle of an accelerometer and digital camera, and their data acquisition process
- Interpret the concept of image processing techniques through signal processing theory
- Develop Python programs to process and analyze 2D and 3D optical data for structural assessment
- Demonstrate how to implement machine learning algorithms in solving real-world problems
- Explain the working principle of neural network and neural radiance field algorithms
- Devise innovative smart structure technology for civil engineering applications and research

Course Outline

Class	Topics (lecture slide)	Lecture	Notebook	Colab	Load	ETF	Task
C01	Introduction				1	Jan 08	Task01
C02	Data Acquisition		Notebook	Open in Colab	1	Jan 10	
C03	Signal Processing I				1	Jan 15	Task02
C04	Signal Processing II				1	Jan 17	
C05	Signal Processing III				1	Jan 22	
C06	Modal Analysis				1	Jan 24	Task03
C07	Digital Image				0.5	Jan 29	
C08	Projective Geometry				2	Feb 05	
C09	Linear Filtering				1	Feb 07	Task04
C10	Image Morphology				1	Feb 12	
C11	Edge Detection I				1	Feb 14	
C12	Edge Detection II				1	Feb 21	Task05
C13	Feature				2	Feb 28	
C14	RANSAC				1	Mar 04	Task06
C15	Camera Model				0.5	Mar 04	
C16	Two-view Geometry				1	Mar 06	
C17	Structure From Motion				0.5	Mar 11	Task07
C18	Intro. of Machine Learning				0.5	Mar 11	
C19	Gradient Descent				0.5	Mar 13	
C20	Training Linear Model				0.5	Mar 13	
C21	Neural Network				1.5	Mar 20	Task08
C22	Convolutional Neural Network				1.5	Mar 25	
C23	Neural Radian Field (NeRF)				2	Apr 02	Task09

Introduction

Signal Processing (1D)

Image Processing (2D)

3D Data Processing (3D)

Machine Learning

Prerequisite

- It is crucial for students to possess a solid grasp of **linear algebra** and **probability concepts**.
- Developing **expertise in Python programming** is a fundamental requirement.
- Students are required to be well-versed in **Markdown scripting**, adept at crafting **mathematical equations using LaTeX**, and proficient in using **Jupyter Notebook** for the submission of task assignments.

First Day Task

- Choose and install an IDE suitable for Python development, such as Visual Studio Code.
- Follow the steps to configure a Jupyter Notebook environment on your system.
- Ensure the installation of necessary Python libraries, including but not limited to numpy and PIL (Python Imaging Library).
- For exporting documents to PDF, install TeX, a typesetting system, and Pandoc, a document conversion tool.

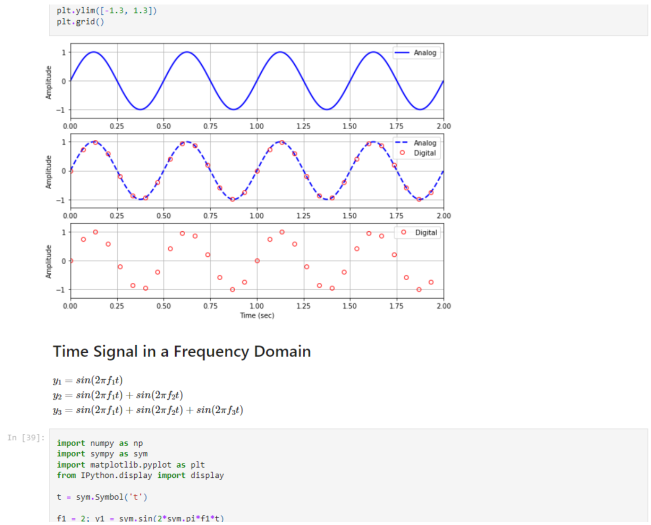
How To Study This Course

Class	Topics (lecture slide)	Lecture	Notebook	Colab	Load	ETF	Task
C01	Introduction				1	Jan 08	Task01
C02	Data Acquisition		Notebook	Open in Colab	1	Jan 10	
C03	Signal Processing I				1	Jan 15	Task02

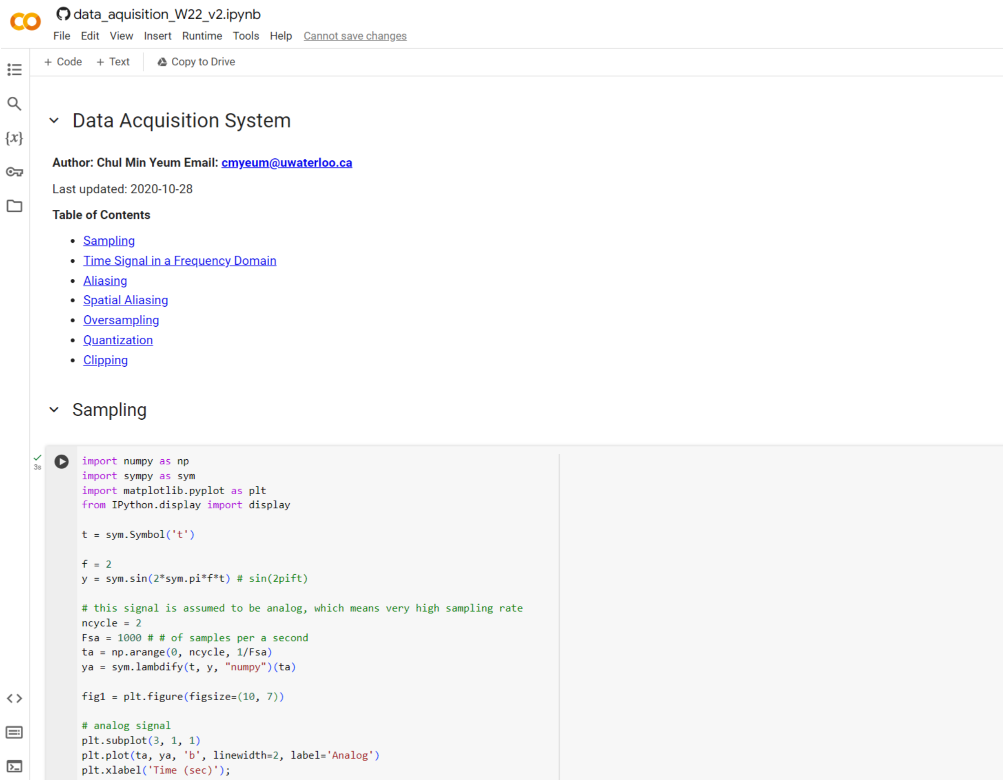
Lecture slide

Lecture video

Jupyter Notebook at Github



Executing the Jupyter notebook in Google Colab



Tasks

There will be **9 tasks** and **1 Quiz** and they will be posted on this course website weekly or bi-weekly. **The instructor encourage students to work in groups through collaborative learning, but to submit their assignments individually.** The task will have programming components or photography components, where students will use their own camera to capture and process their own images and discuss the results. Students are supposed to complete all tasks and turn their works in by the due date. You can access the best reports for the assignments in previous years from **w2022**, **w2021**, **w2020**, and **w2019**. The problems will be similar to the ones in the previous assignments. However, **the students must not copy and paste the codes or texts in those reports.** Also, some answers in the model report are not correct.

Students are required to use **Python** for all assignments. Your source code should be well-organized and thoroughly commented. Submission must include both the source code (along with any data used) and a report. The report should be initially written in **Jupyter notebook** and then converted to PDF format. Each assignment will come with its specific submission guidelines. Please note that your grade will be based on the PDF report. Ensure that it includes all necessary figures and texts before submission.

Tasks (Continue)

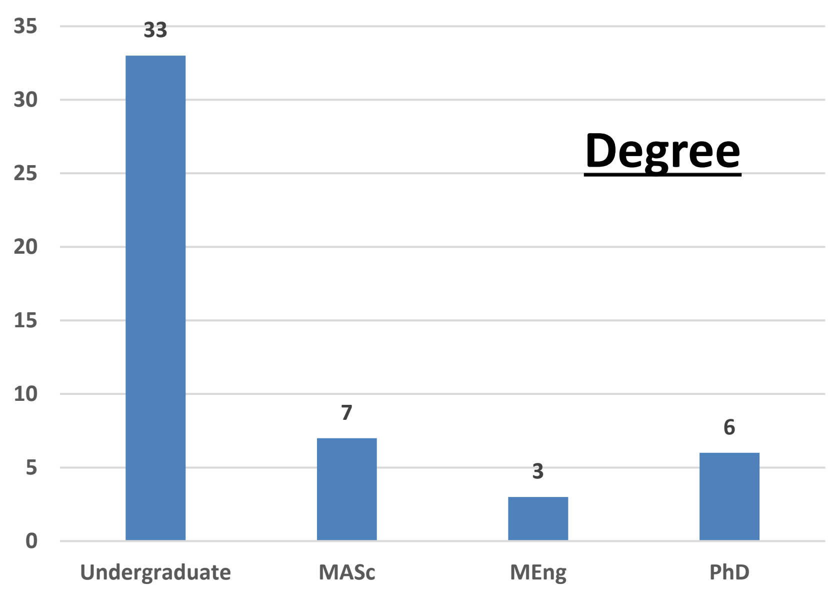
Regarding late submissions, you are allowed a **maximum one-week** extension for up to **three of the first eight assignments**. However, the final assignment must be submitted on time. **Exceeding three late submissions will result in a score of zero for the fourth late assignment.** Be mindful of deadlines; extensions beyond this policy will only be considered under exceptional circumstances and may incur a penalty.

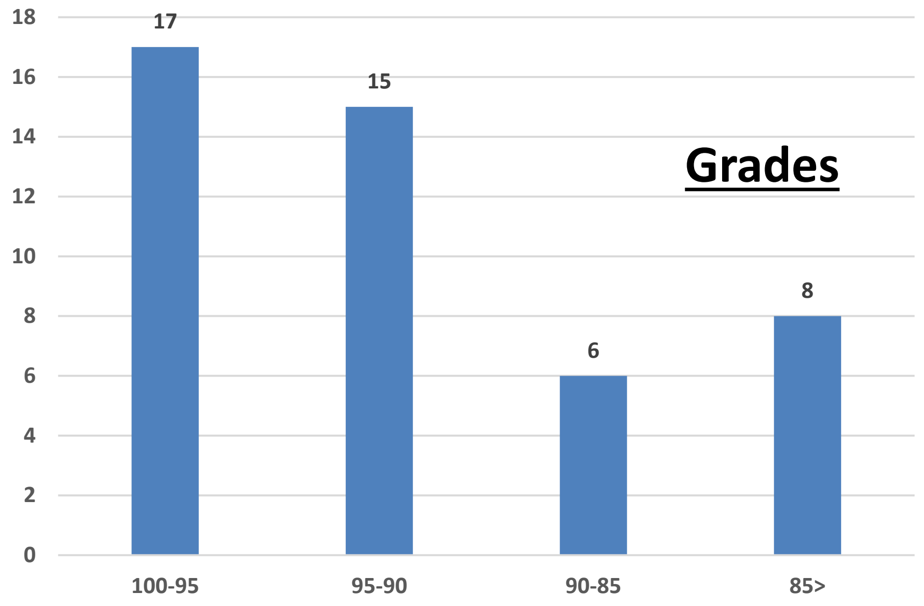
Graded reports will be sent via email. Additionally, sample solutions will be discussed in class, and with their permission, outstanding student reports may be shared on the class webpage.

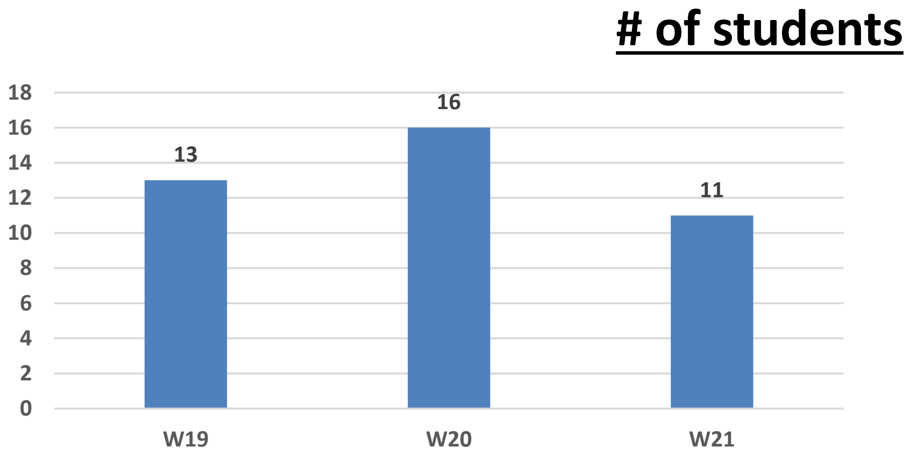
Your final grade in this course depends significantly on your assignment scores. Therefore, not submitting homework could adversely affect your overall grade. **If you're facing difficulties with the assignments, don't hesitate to contact the instructor or TA for help.**

Task	Topics	Mark	Announcement	1st Deadline	2nd Deadline
Task01	Basic Image Processing	5	Jan 08, 2023	Jan 18, 2023	Jan 25, 2023
Task02	Signal Processing I	5			
Task03	Signal Processing II	8			
Quiz01	Quiz	7			
Task04	Homography	15			
Task05	Image Processing	10			
Task06	Feature Matching & RANSAC	15			
Task07	Multiview Geometry	15			
Task08	Neural Network	15			
Task09	Neural Radiance Field	10			

Statistics from the Course in W19-W22







Communication

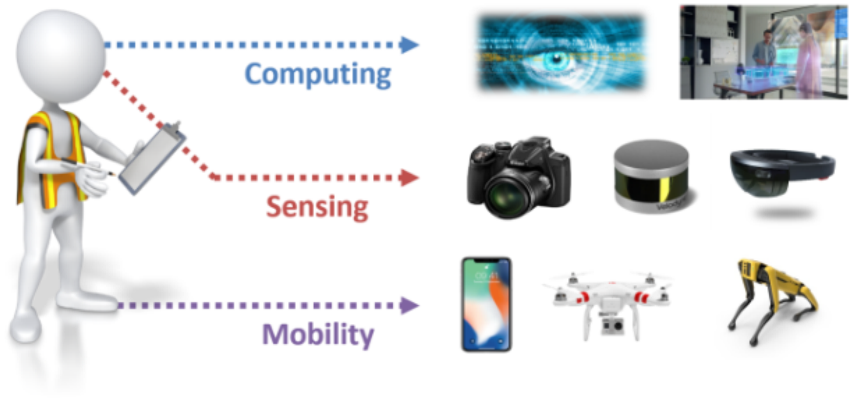
All communication will be made through [this course website](#), especially for this web page. The instructor will make a note in the "Announcement" section if there is an update on the web page. Students can configure email notification for by "watching" this course website or use a version control system for tracking its changes. Thus, **students are responsible for checking the website regularly** for any relevant course information or announcements.

In this course, both the instructor and the students are encouraged to engage in online discussions to create and facilitate a collaborative learning experience. Students are invited to ask questions and answer them, and share their knowledge and resources. **Please direct your communication to a *Discussion* board (tab) on this website.** However, if there is a good reason not to use the discussion forum (e.g. personal matters, a question that might reveal your solution of your report, etc.), please directly contact the instructor via email (cmyeum@uwaterloo.ca). Or, you can feel free to send messages the instructor or TA through Microsoft TEAM. You can check out this website. If possible, the instructor and TA prefer to use the discussion forum because questions and responses can be shared to the other students.

Course Website in Github

README

CIVE497/700: Smart Structure Technology (Winter, 2024)



Instructor: Chul Min Yeum (E2-2313)
Class: Mon and Wed, 08:30AM to 9:50AM at E2-2350
Email: cmyeum@uwaterloo.ca
Office Hours: Mon and Wed 10 to 11AM at E2-2313 (or after each class)

Last updated: 2024-01-01

Previous offerings of this course

- Smart Structure Technology (Winter, 2022)
- Smart Structure Technology (Winter, 2021)
- Smart Structure Technology (Winter, 2020)
- Smart Structure Technology (Winter, 2019)

https://help.github.com/en/github/receiving-notifications-about-activity-on-github/watching-and-unwatching-releases-for-a-repository

https://www.youtube.com/watch?v=77W2JSL7-r8

Previous Task Assignment with Model Report

Task	Topics
Task0	MATLAB and Digital Image Processing Tutorial Best report (Kareem Mostafa)
Task1-1	Signal Processing I Best report (Laurent), Best report (Wildt)
Task2	Camera Sensor Best report (Tianyi), Best report (Juan)
Task1-2	Signal Processing II Best report (Steven)
Task3	Homography Best report (Hongyi)
Task4	Image Filter (No best report)
Task5	Image Stitching Best report (Laurent)
Task6	3D Measurement using SfM
Task7	Scan Registration
Task8	Neural Network

https://github.com/chulminy/CIVE497-CIVE700/tree/master/w2019#tasks

Task	Topics
Task1	Programming Practice
Task2	Signal Processing I Best report (Saeed Ardakani)
Task3	Signal Processing II Best report (Charlotte Mei), Best report (Aleksandar Jakovljevic)
Task4	Digital Image Processing & Camera Sensor and Digital Image Best report (Hana Bregman), Best report (Saeed Ardakani)
Task5	Homography Best report (Armina Soleymani), Best report (Saeed Ardakani)
Task6	Image Filter & Edge Detection Best report (Jasmine Zou), (Aleksandar Jakovljevic), (Saeed Ardakani)
Task7	Image Stitching & RANSAC Best report (Saeed Ardakani)
Task8	Neural Network Best report (Saeed Ardakani)

https://github.com/chulminy/CIVE497-CIVE700/tree/master/w2020#tasks

Task	Topics
Task01	Programming
Task02	Signal Processing 1 Best report: (Kin Long Li)
Task03	Signal Processing 2 Best report: (Noreen Gao), (Wilson Carofilis)
Task04	Digital Image
Task05	Homography Best report: (Noreen Gao)
Task06	Image Processing Best report: (Jing Zhang)
Task07	Feature Matching & RANSAC
Task08	Multiview Geometry (SfM)
Task09	Neural Network

https://github.com/chulminy/CIVE497-CIVE700/tree/master/previous/w2022#tasks

Policy for Generative Artificial Intelligence

Generative artificial intelligence (GenAI) trained using large language models (LLM) or other methods to produce text, images, music, or code, like Chat GPT, DALL-E, or GitHub CoPilot, **may be used for assignments in this class with proper documentation, citation, and acknowledgement.** Recommendations for how to cite GenAI in student work at the University of Waterloo may be found through the Library: https://subjectguides.uwaterloo.ca/chatgpt_generative_ai. **Please be aware that generative AI is known to falsify references to other work and may fabricate facts and inaccurately express ideas.** GenAI generates content based on the input of other human authors and may therefore contain inaccuracies or reflect biases.

In addition, you should be aware that the legal/copyright status of generative AI inputs and outputs is unclear. Exercise caution when using large portions of content from AI sources, especially images. More information is available from the Copyright Advisory Committee: https://uwaterloo.ca/copyright-at-waterloo/teaching/generative-artificial-intelligence

You are accountable for the content and accuracy of all work you submit in this class, including any supported by generative AI.

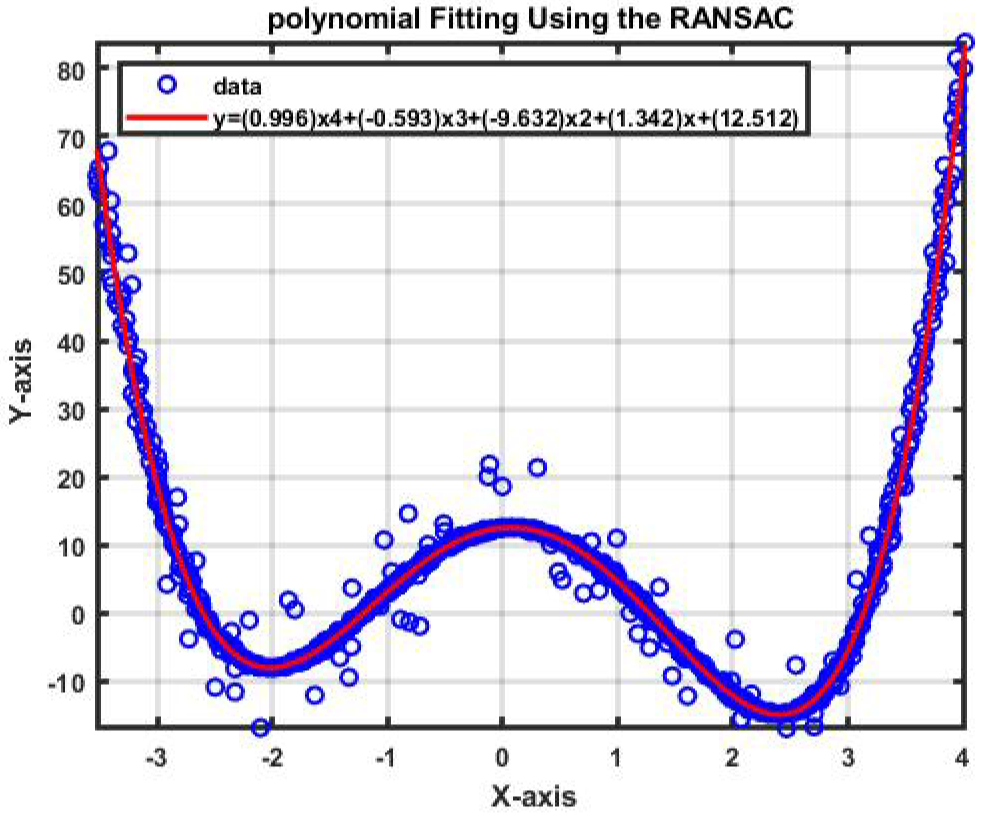
Remember that the instructor is aware that the students are using GenAI !!

Tasks in W19

Hanging a nice picture

Image-based measurement

Tasks in W19 (Continue)



Polynomial fitting

Book detection

Tasks in W20

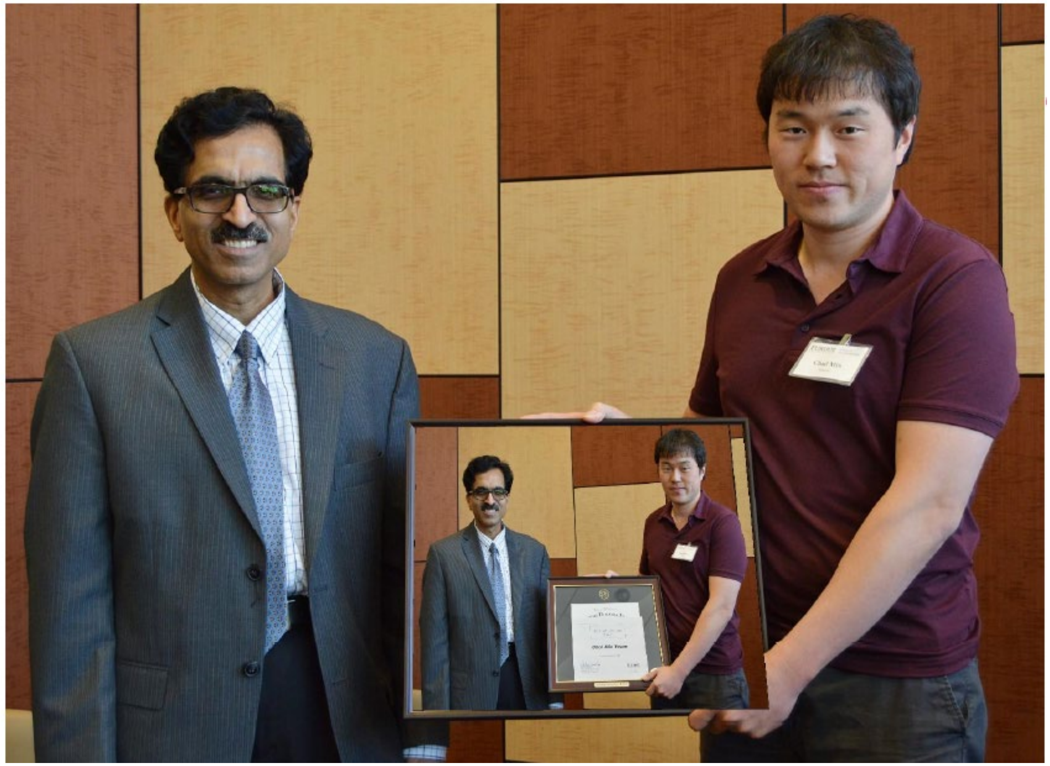
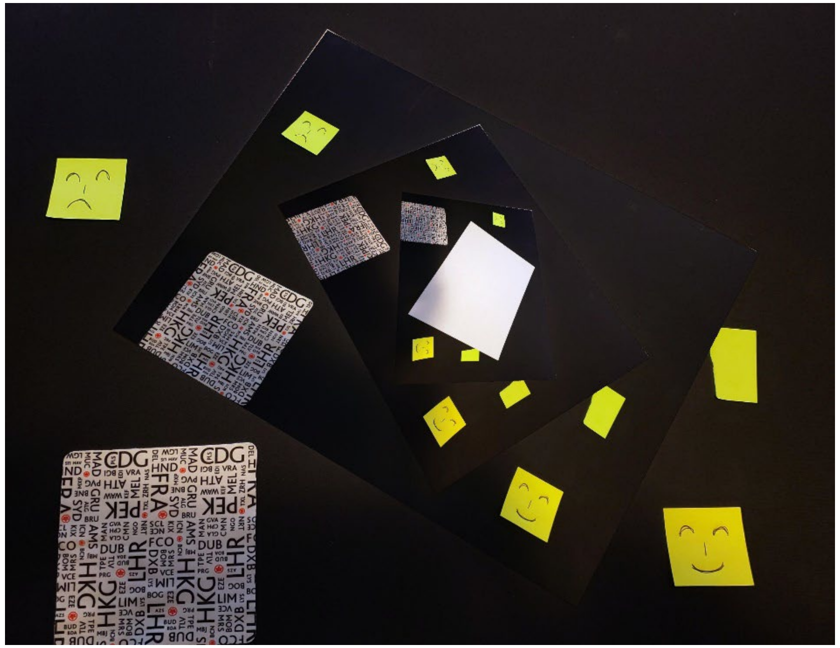


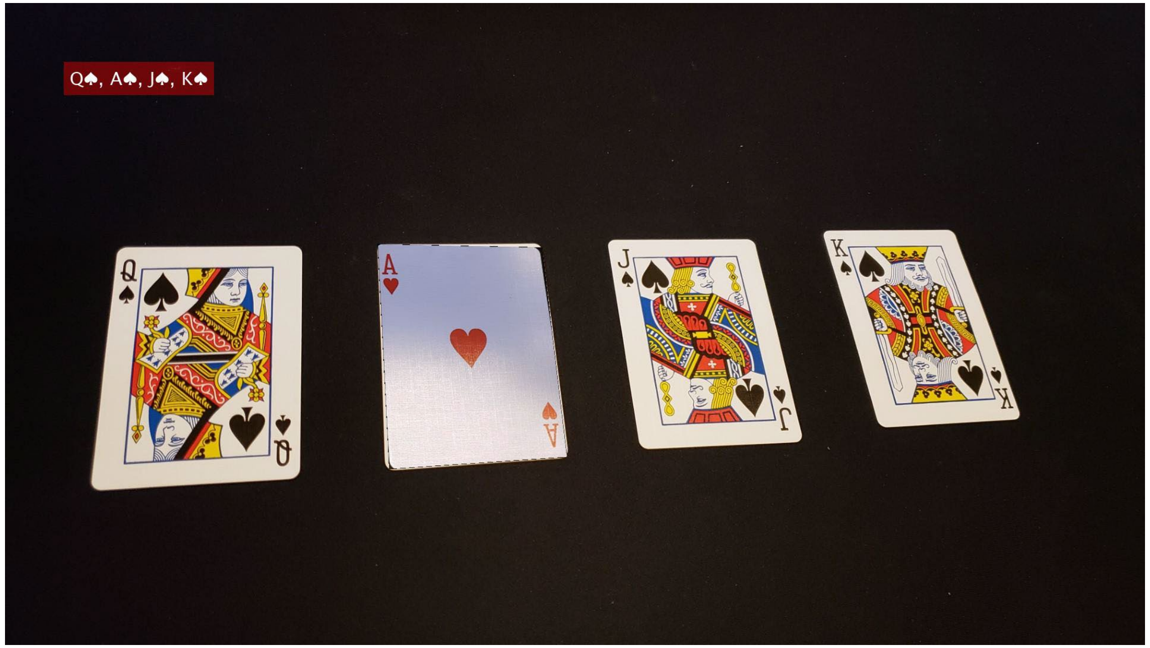
Image Overlay

Image Stitching

Tasks in W21

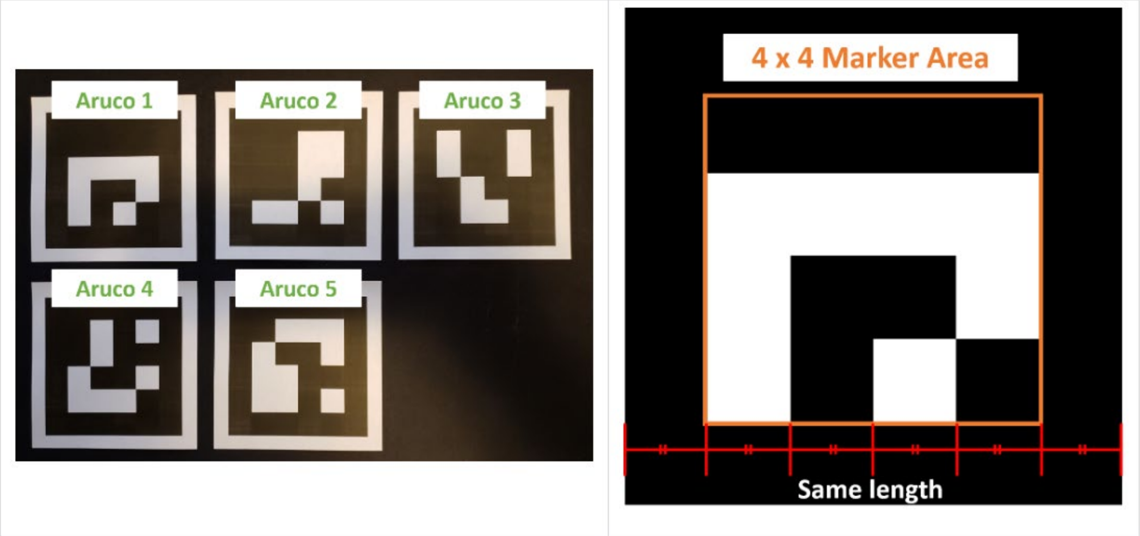


Picture in Picture



Feature Detection/Matching

Tasks in W22



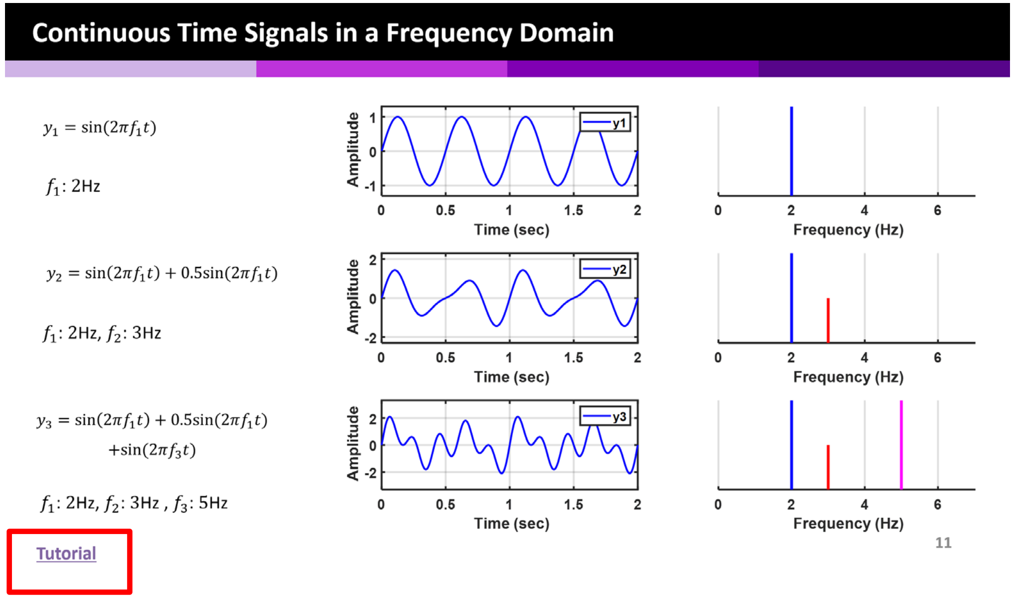
(a) Five Aruco markers used in this problem

(b) a 4 x 4 maker design

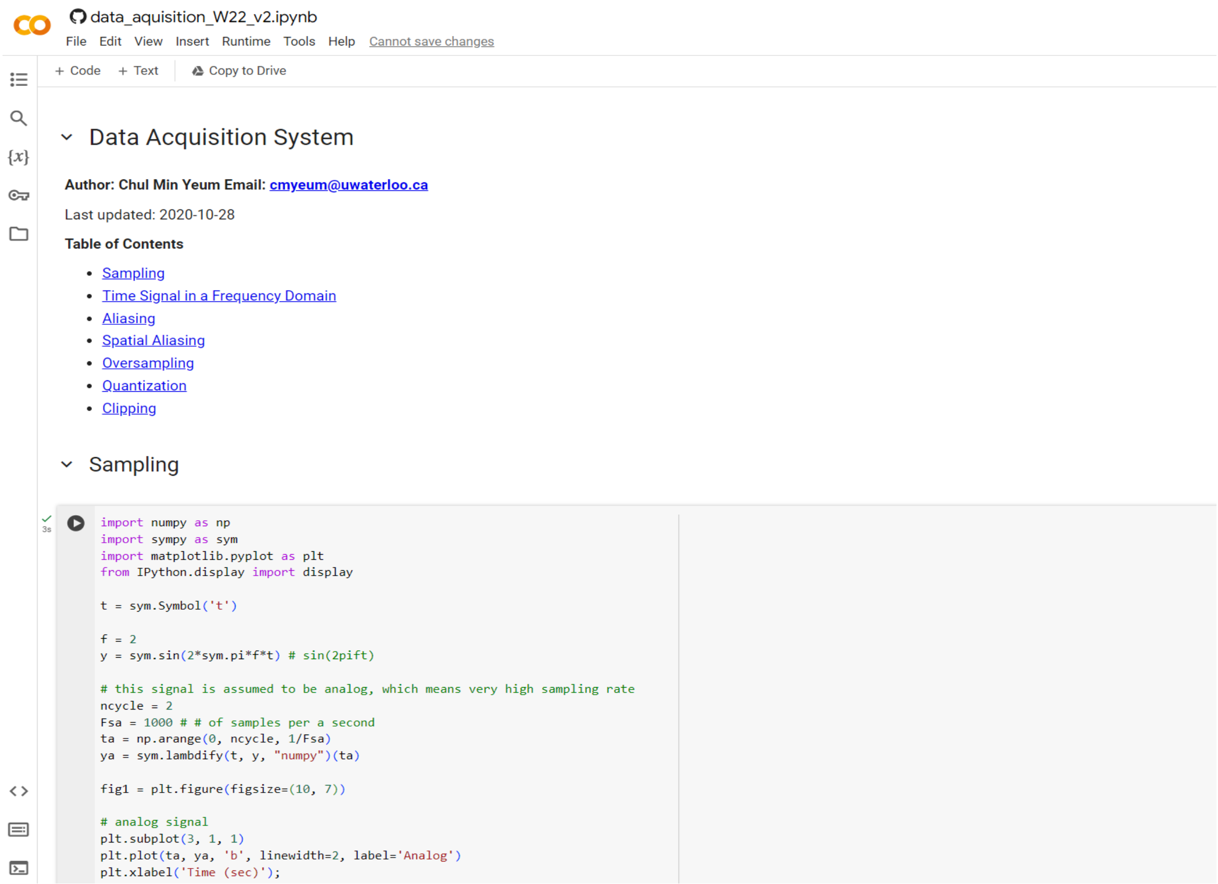
Marker ID detection

Image Overlay

Tutorial Code



Tutorial codes are very useful to understand the concept as well as doing the task assignments



If there is "tutorial" in the slide, you can see a tutorial code corresponding to the graphs or figures

Some Notes

- This course promises to be **both challenging and enjoyable.** As your instructor, I am committed to addressing your queries and facilitating your learning journey. Please feel free to ask questions either through the course website or directly to the teaching assistants and myself. **It's completely normal to find some topics confusing, so don't get discouraged.**
- The task assignments will progressively become more demanding. Remember, completing these assignments is mandatory as there are no base marks.
- I encourage you to think about how the knowledge gained here can be applied to your present or future research or professional endeavors.
- **Tutorials will prove invaluable in your study of these topics.** Prepare yourself for a rigorous course that will require a significant investment of your time in studying and completing homework.
- I also recommend reviewing the top reports from previous years for guidance, but be mindful not to plagiarize their content in your own work.
- Effective time management is crucial to ensure timely submission of your reports.

The Most Cited Papers in Computer Vision

Distinctive image features from scale-invariant keypoints
DG Lowe - International journal of computer vision, 2004 - Springer
… for extracting **distinctive** invariant **features from images** that … The **features** are invariant to **image** scale and rotation, and are … The **features** are highly **distinctive**, in the sense that a single …
☆ Save 99 Cite Cited by 73304 Related articles All 141 versions

Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography
MA Fischler, RC Bolles - Communications of the ACM, 1981 - dl.acm.org
… We introduce a new paradigm, **Random Sample Consensus** (RANSAC), for fitting a model to experimental data; and illustrate its use in scene analysis and automated cartography. The …
☆ Save 99 Cite Cited by 32289 Related articles All 9 versions

[BOOK] **Multiple view geometry** in **computer vision**
R Hartley, A Zisserman - 2003 - books.google.com
… Despite these negative remarks, **Computer Vision** … rough terrain using **computer vision** technology was demonstrated … what one could call **geometric Computer Vision**. This includes the …
☆ Save 99 Cite Cited by 34014 Related articles All 21 versions

Imagenet classification with deep **convolutional neural networks**
A Krizhevsky, I Sutskever… - Advances in **neural** …, **2012** - proceedings.neurips.cc
… **convolutional neural networks** to date on the subsets of ImageNet used in the ILSVRC-2010 and ILSVRC-**2012** … We wrote a highly-optimized GPU implementation of 2D **convolution** and …
☆ Save 99 Cite Cited by 123733 Related articles All 111 versions »

[PDF] A **threshold selection method** from **gray**-level **histograms**
N Otsu - IEEE transactions on systems, man, and cybernetics, 1979 - cw.fel.cvut.cz
… **method** to establish an appropriate criterion for evaluating the "goodness" of **threshold** from a … elementary case of **threshold selection** where only the **gray**-level **histogram** suffices without …
☆ Save 99 Cite Cited by 51372 Related articles All 29 versions »

A **computational approach** to **edge detection**
J Canny - IEEE Transactions on pattern analysis and machine …, 1986 - ieeexplore.ieee.org
… **edge detector** performance improves considerably as the operator point spread function is extended along the **edge**… of the **edge detection** problem, we decided that **edges** would be …
☆ Save 99 Cite Cited by 43684 Related articles All 25 versions

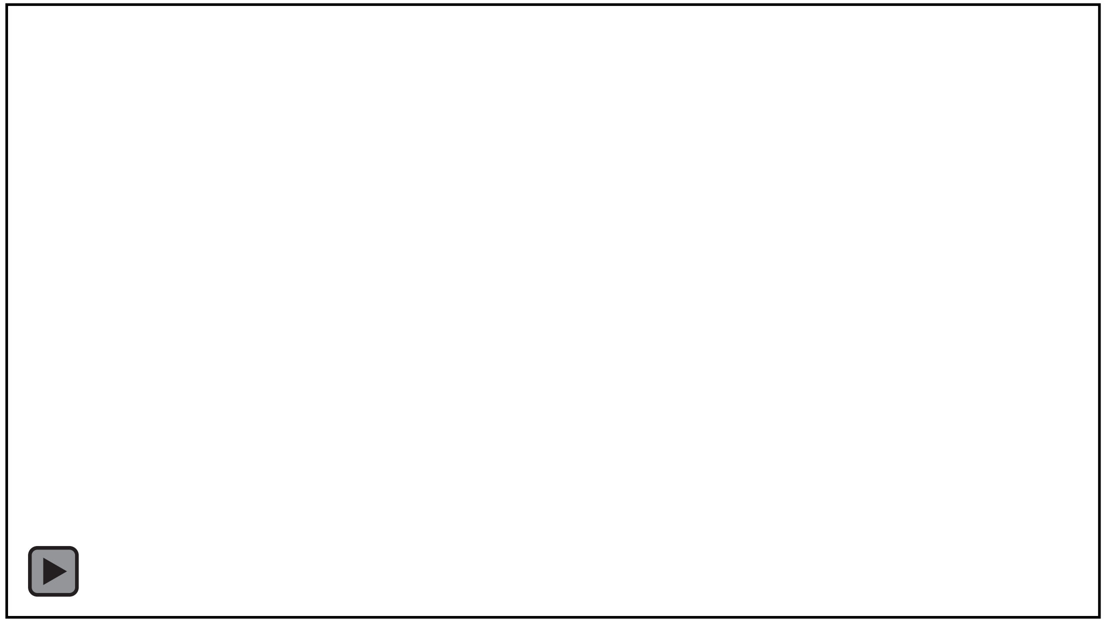
- https://computervisionblog.wordpress.com/2016/06/19/the-most-cited-papers-in-computer-vision-and-deep-learning/
- https://computervisionblog.wordpress.com/2012/02/10/the-most-cited-papers-in-computer-vision/

Remarks

It is not that I’m so smart.

It is just that I stay with problems longer.

- Albert Einstein



https://www.youtube.com/watch?v=G2PJdmG2ICA