CS598 Fall: Advanced Topics in Robot Perception

Shenlong Wang
Aug 25, 2021

Many slides are adapted from Saurabh Gupta, Kris Hauser, Yuke Zhu, Frank Delleart, Shuran Song
Today’s Agenda

- Intro to Robot Perception
- Course Outline
- Logistics
- Get to Know Each Other
Why Should You Take This Course?
Robots are Cool!
Robots are Cool!
Robots are Cool!

The software is replaced by the Paparazzi UAV open-source autopilot project
Robots are Cool!

BionicBird MetaFly
Robots are Cool!

Dragon University of Tokyo
Robots are Cool!

Dash! Yonkuro

Robots are Useful!

NASA
Robots are Useful!

Alibaba
Robots are Useful!
Robots are Useful!
Robot Tasks: Navigation

- Determine the robot's current position.
- Determine the goal location and plan a trajectory.
- Reach a goal location safely.

Image credit: Skydio, Uber, Boston Dynamics
Robot Tasks: Manipulation

- Determine the other objects’ pose.
- Determine a series of movement to reach the goal.
- Execute the motion without breaking things.
Key Ingredients of a Robot

Observation → Perception → Planning → Control → Action

Observed Images → 6DOF Pose → Grasp Motion Planning

Image credit: Saurabh Gupta
Key Ingredients of a Robot

Observation → Perception → Planning → Control → Action

World
Key Ingredients of a Robot

Planning
Observation
Control
Perception
Action

Image credit: Saurabh Gupta
Key Ingredients of a Robot

1. Observation
2. Perception
3. Planning
4. Control
5. Action

Observed Images → 6DOF Pose → Grasp Motion Planning

Image credit: Saurabh Gupta
Robot Perception

Sense, Interpret and Understand the Physical Environment

Image credit: Google, Waymo Open Dataset, ScanNet
Perception: Self-Driving

- Perceive other objects
- Localize itself
- Perceive surrounding scene
Perception: Manipulation

Detect objects

Group instances

Reconstruct geometry

Image credit: PoseCNN Yu et al. 2018
What Makes Robot Perception Special?

- **Embodied**: Robots have physical bodies, situated in the physical world, and experience the world directly.

- **Active**: Robots are active perceivers. It knows why it wishes to sense, and chooses what to perceive, and determines how, when and where to achieve that perception.
Desiderata for Robot Perception

- **Robust**: handling unknowns and observation noises
- **Efficient**: runs in real-time on an embodied device
- **Active**: suitable towards action goal; able to move and see better
- **Verifiable**: have a form of guarantees; can tell when it failed / uncertain
Why Robot Perception is Not There Yet?

- object variation
- environment uncertainty
- adaptation

Image credit: Yuke Zhu
Opportunities

Algorithms

Dataset and Simulation

Sensing

Hardware Support

Image credit: Yuke Zhu, Nvidia, Carla, Boston Dynamics
Why You Should Take This Course?

- Robots are cool!
- Robots are useful!
- Robot perception needs your help to become better.
- And we have the tools!
Learning Objectives

- Understand **technical challenges** arising from building perception algorithms. Understand the technical and societal impact of perception for building robust autonomy in the real world.
- Get familiar with **mathematical toolkits** and **state-of-the-art** robot perception algorithms.
- Be able to develop **potential novel solutions** in addressing these challenges and build perception algorithms for real-world systems.
Course Content

- **Chapter I Fundamentals**: basic knowledge and tools for perception
- **Chapter II Case Studies**: crucial robot perception tasks
- **Chapter III Frontiers**: unsolved challenges and state-of-the-art progresses
Fundamentals: Transforms and Sensing Models

Lecture 2
Poses, Transforms, Kinematics

Lecture 3
Sensing I: LiDAR, Radar, GPS, IMU, Tactile, ... etc

Lecture 4
Sensing II: Cameras, Stereo, Perspective Geometry, Epipolar Geometry
Fundamentals: Mathematical Toolkits

Lecture 5: Deep Learning

Lecture 6: 3D Representations

Lecture 7: Graphical Models and Nonlinear Optimization

Lecture 8: State Estimation and Bayes Filters
Case Studies: Spatial Perception

Lecture 9: Localization with a Map

Lecture 10: Depth Sensor SLAM

Lecture 11: Visual SLAM
Case Studies: **Scene** Understanding

Lecture 12: Image Segmentation

Lecture 13: 3D Segmentation and Semantic Fusion
Case Studies: **Object** Perception

Lecture 14: Detection and Tracking

Lecture 15: 6-DoF Pose and Affordance
Frontiers: Perception in a Moving World

Lecture 16: Motion Estimation

Lecture 17: Motion Forecasting
Frontiers: Perception in an Open World

Lecture 18: Modeling Instances from Unseen Categories

Lecture 19: Modeling Unseen Tasks / Environments
Frontiers: Perception and Action

Lecture 20: See to Act

Lecture 21: Act to See
Frontiers: Perception and **Simulation**

Lecture 22: Classic Simulation, Sim2Real

Lecture 23: Data-Driven Simulation
Frontiers: Perception with Guarantees

Lecture 23: Prune to Certain Noises/Attacks

Lecture 25: Know whether it succeeds

Lecture 26: Know whether it is confident

Succeed!
Frontiers: Perception with **Multiple Modalities**
Guest Speakers

Luca Carlone
Associate Professor, MIT
SLAM, and certifiable correct perception

German Ros
Research Scientist, Intel
Lead of Carla and Open3D
Logistics: Schedule

- Time: 2:00-3:15pm CT, Wednesday and Friday
- Location: Online (Zoom links on course website)
- Office Hour: after each lecture, same zoom with breakout rooms
Relevant Courses at UIUC

- **CS598 3D Vision** by Derek Hoiem.
- **CS498 Mobile Robotics** by Girish Chowdhary.
- **CS598 Advanced Computational Topics in Robotics** by Kris Hauser.
- **CS598 Autonomous Vehicles** by David Forsyth.
- **ECE598 Robot Learning** by Saurabh Gupta.
Grading Policy (Tentative)

- **Participation (10%)**. Participation in in-class discussion and on Piazza.
- **Paper Presentations (20%)**. Presenting 1-2 research topics in class.
- **Paper Reviews (20%)**. Writing reviews for research papers.
- **Final Project (50%)**. Completing a research project.
### Logistics: Reading

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<th>9/24</th>
<th>Lecture #9 (TBD):</th>
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<tr>
<td></td>
<td><strong>Spatial Perception: Map-based Localization</strong></td>
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<td>- Map Representations</td>
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<td>- Registration and Matching</td>
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- Probabilistic Robotics, Ch. 9
- [R] Levinson et al., *Robust vehicle localization in urban environments using probabilistic maps*
- [R] Sarlin et al., *From Coarse to Fine Robust Hierarchical Localization at Large Scale*
- Barsan et al., *Learning to Localize Using a LiDAR Intensity Map*

[R]: must read; choose to write reviews;  
Others: optional readings, demos, tutorials, book chapters, etc.
Logistics: Reviewing

- Each student is required to submit at least **20 reviews**
- Each review will be worth **1%** of the total grade, summing up to **20%** of the course grade for paper reviewing.
- Students are recommended to submit one paper review per class. However, it is not a must.
- Reviews must be submitted **before the day** of lecture.
- Four-point system (100, 90, 80, 0)
- Instructor will only give constructive feedbacks to review comments if it needs necessary improvement.
Logistics: Presentation

Each student will present a research topic in a 30-min slot (25min + 5min QA)

- Map-based Localization
- Visual SLAM
- LiDAR SLAM
- 2D Detection
- 2D Segmentation
- ...
- Active Perception
- Sim2Real
- ...
Logistics: Presentation

The presentations will be graded in the following aspects:

● Clarity of presentation;
● Literature reviews and the key challenges addressed by this work;
● Analysis of the strengths and weaknesses of the research;
● Discussions of potential future research directions and applications;
● Response to questions and engage in open-ended discussions (in-class and on Piazza).

Four-point system (100, 90, 80, 0)
Logistics: Final Projects

- Projects should be done either individually or in a team of two students. Shenlong will discuss with you on your ideas and the execution throughout the semester.

- **Project Proposal**: 2 pages excluding references (15%)
- **Mid-term Presentation**: 5-min presentation on project update (15%)
- **Final Report**: 8 pages excluding references (50%)
- **Final Presentation**: 12-min talk + 2-min Q&A (20%)
- **Teaser Video** (optional): 3-min teaser video (10% bonus)
- All write-ups should use the [RSS latex template](#).
Course Reschedule

Sept-1 Wed course needs to be scheduled.

We will have a make up session for mid-term presentation.

- Extend one lecture in Oct: Say, extend Oct 20, 2pm to 4:30pm.
- Find another slot in Oct.
Todo List

- Join Piazza forum
- Check course website
- Filling your presentation form
- Ping me with questions on prerequisites
- Enjoy the rest of the day
Tell Us About You
Todo List

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