EECE 5550
Mobile Robotics

Lecture 23: Recent Trends & Advanced Topics

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Plan of the day

- Some robotics applications
- Some research challenges
- Some advanced topics

References:

- A Roadmap for Robotics in US

  https://cra.org/ccc/wp-content/uploads/sites/2/2020/10/roadmap-2020.pdf

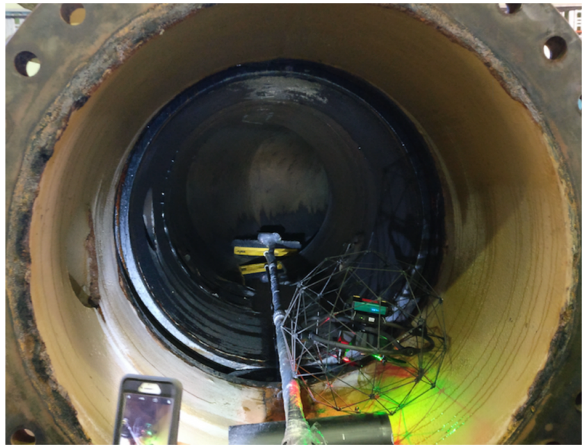
- Past, Present, and Future of Simultaneous Localization and Mapping: Towards the Robust-Perception Age

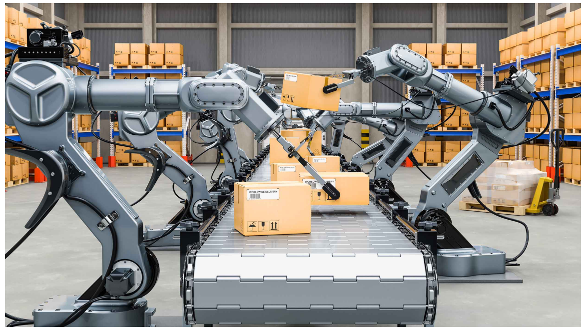
  https://ieeexplore.ieee.org/abstract/document/7747236?casa_token=kVSc92upeKMAAAAA:TY8JXRETpAIZ1qcFPV8f8p70oSpx2N85GSBWS7zLTwbJ7SNSKrjc_jWHjEqk5_4wUg0egp3Pfbw

Robotics

- Dirty, dull, and dangerous tasks

- Core areas:
  1. Mechanics
     - Modeling and design of robotic systems
  2. Control
     - Moving robots
  3. Perception
     - Perceiving, comprehending, and reasoning about the surrounding area
  4. Artificial Intelligence
     - Making decisions and learning that minimize human interventions





Autonomous Driving

Levels of autonomy

1. Driver assistance (e.g., automatic cruise control)
2. Partly automated driving (assistance about acc./braking/steering)
3. Highly automated driving (the driver allows the system to take over)
4. Fully automated driving
5. Full automation (no driver)

Some challenges:

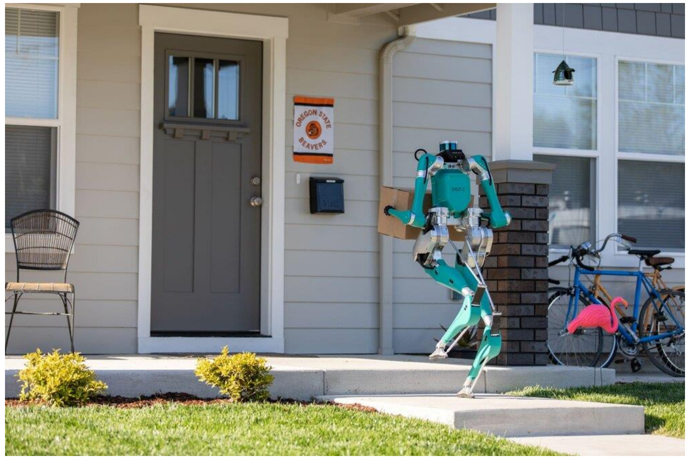
- Sensing/perception issues (bad weather, low light, pedestrian etc.)
- Interaction with humans
- Liability issues
- Sensor interference with other autonomous cars

Last Mile Delivery

A route planning problem that needs to take into account greater number of stops, smaller shipment sizes, size/value of deliveries, deviations from planned routes, speed, etc.

Some challenges:

- Combinatorial optimization problems
- Complexity increases with the consideration of uncertainty
- Adapting to unexpected environmental factors
- Heterogenous systems <-> individual challenges
- Perception challenges



Agility Robotics

Amazon Robotics

Urban Air Mobility

- A new means of transportation to reduce traffic congestion
- Use of small, highly automated aircraft to carry passengers or cargo at lower altitudes in urban and suburban areas

Some challenges:

- Design of vertical take-off and landing vehicles
- Safety (perception/decion-making)
- Infrastructure
- Air traffic management

Precision Agriculture

Using robots that can assist decision-making using high-technology sensors and analysis tools to improve crop yields.

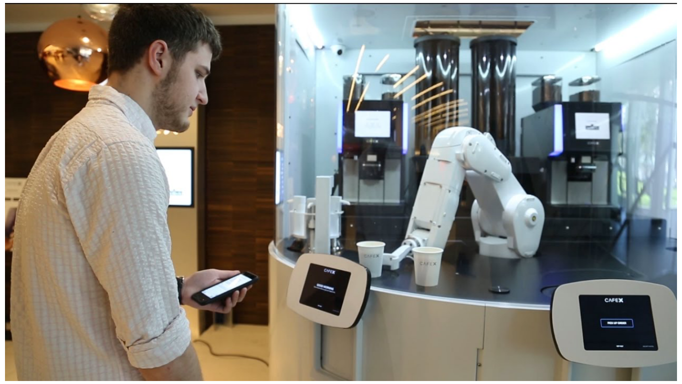
Some challenges:

- Safety
- Perception – challenging environmental conditions
- Operation under changing environment
- Long-horizon autonomy
- Teaming
- Various capabilities (locomotion, manipulation)
- Drone as a service

Service Robotics

Robots assisting human beings

- health care and rehabilitation; commercial cleaning; household tasks; fast food service; gasoline station attendant; aiding the handicapped and the elderly



Research challenges:

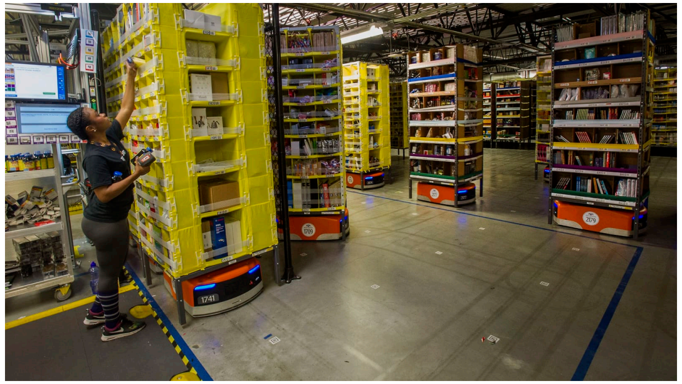
- Safety (e.g., mobile obstacles)
- Human-robot interaction (e.g., communication, assistance)
- Operation in unstructured environment (perception and decision-making)
- Robust manipulation

Logistics

Robots used to automate product flows, maximize safety, and boost productivity in warehouse operations.

Some challenges:

- Multi-robot coordination
- Safety
- Robust manipulation and grasping (packing/unpacking boxes)
- Robust computer vision for recognition



Amazon Kiva robots

Boston Dynamics

A summary of some major research challenges

1. **Mechanics**
    - Miniaturization
    - High precision actuation
    - Energy
    - Material/fabrication
    - Efficient locomotion/manipulation
2. **Control**
    - Safety guarantees in systems with high degrees of freedom
    - Efficient computation
    - Distributed control
3. **Perception**
    - Reliability
    - Speed
    - Activity recognition
4. **Artificial Intelligence**
    - Robust planning
    - Resilience/adaptability
    - Learning
    - Scalability
    - Complex mission specifications
    - Teaming (human-robot, robot-robot)

Depending on your interests, you can take more depth courses to learn more about these…
(Mathematics, Coding, Specialized area)

Dependable **A**utonomy **L**ab

PI: Derya Aksaray, Assistant Professor, Department of Electrical and Computer Engineering
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Our objective: Design provably-correct algorithms for efficient, resilient, and safe operation of autonomous systems under complex objectives/constraints

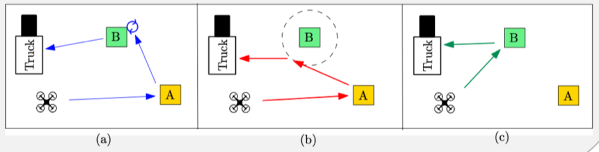
Resilient Autonomy

A disturbance may cause mission failure.

- Termination
- Recovery

Goal: How to achieve minimal relaxations of the mission so that the system can achieve it with its current capabilities and surroundings?

Benefit: Mission execution after a failure with min human intervention



Reinforcement Learning under Complex Objectives/Constraints

Standard RL problem:

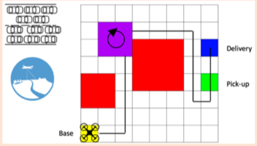
- Objectives as sum of rewards
- No constraint satisfaction guarantee throughout learning.

Goal: How to guarantee learning the optimal policy while a desired constraint is satisfied during learning?

Benefit: Multi-use of autonomous sys.

Objective: Learn a policy to stay in the high reward region

Constraint: Satisfy "first go to pick-up then go to delivery" with a prob. greater than $Pr_{desired}$ during learning.



Planning in Semantically Uncertain Environments

Complex specifications: spatio-temporal-logical properties (e.g., "First go to A, then go to B")

Semantically uncertain environments (e.g. , initial belief on where regions A and B can be)

Goal: How to guarantee the accomplishment of complex missions in semantically uncertain environments?

Benefit: Mission execution with performance guarantees in initially unknown environments

Honeywell DARPA NASA JPL Jet Propulsion Laboratory

Northeastern University
Institute for Experiential Robotics

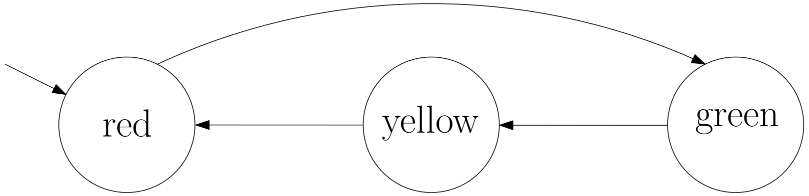
A Classical Problem in Formal Methods

Check if all the possible executions of traffic light will satisfy the specification

"traffic light is green infinitely often, and, once red, the light always becomes green eventually after being yellow for some time"

A Classical Problem in Formal Methods

Mathematical modeling



Model Checking
(Verification)

$$\Box\Diamond \mathit{green} \wedge (\mathit{green} \rightarrow \bigcirc\neg \mathit{red}) \wedge (\mathit{green} \rightarrow \neg \mathit{red}\ U\ \mathit{yellow})$$

Formalization

“traffic light is green infinitely often, and, once green, the light cannot become red immediately, and, once green, the light always becomes red eventually after being yellow for some time”

A Classical Problem in Dynamical Systems

Ultra Stick 120

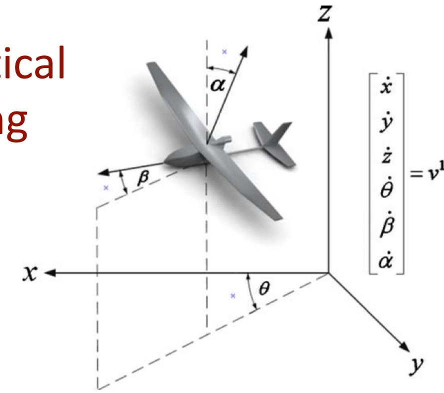
Find the UAV control strategy

"fly from A to B"

A Classical Problem in Dynamical Systems

Ultra Stick 120

Mathematical modeling



$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\\ \dot{\theta}\\ \dot{\beta}\\ \dot{\alpha}\end{bmatrix} = v^1\begin{bmatrix}\cos\theta\cos\beta\\ \sin\theta\cos\beta\\ \sin\beta\\ 0\\ 0\\ 0\end{bmatrix} + v^2\begin{bmatrix}0\\0\\0\\1\\0\\0\end{bmatrix} + v^3\begin{bmatrix}0\\0\\0\\0\\1\\0\end{bmatrix} + v^4\begin{bmatrix}0\\0\\0\\0\\0\\1\end{bmatrix}$$

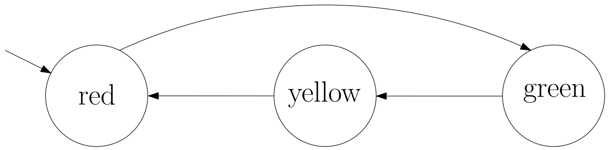
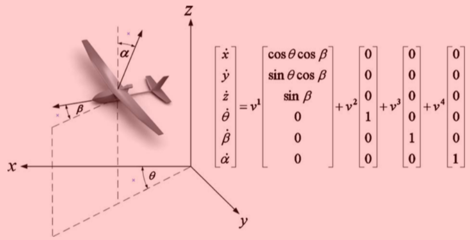
Control

Formalization

Make B an asymptotically stable equilibrium

“fly from A to B”

Formal Methods vs. Dynamical Systems

System		
Model		
Specification	"traffic light is green infinitely often, and, once green, the light cannot become red immediately, and, once green, the light always becomes red eventually after being yellow for some time"	"fly from A to B"

Complex

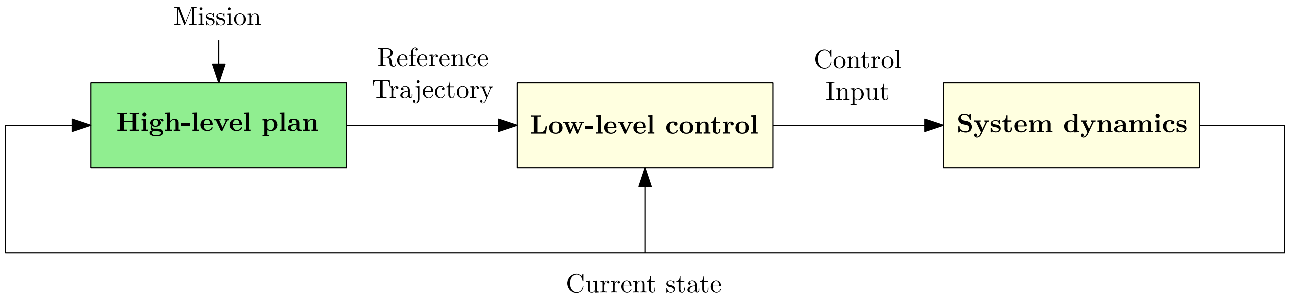
Complex

Formal Methods for Dynamical Systems

Real-life applications

- Control synthesis, verification, learning, etc.
- Real-time monitoring of automobile engines
- Trajectory verification
- Air traffic control ensuring safety
- Software verification

Control synthesis via Formal methods



EECE 5698 – Formal Methods for Dynamical Systems

Course Description: Complex dynamical systems such as robots and cyber-physical-systems consist of hardware and software which closely interact with each other. Traditionally, a closed loop system can be rigorously designed via control theory to achieve specifications like stability or robustness. On the other hand, complex specifications of software can be verified via formal methods. Recently, there has been a great interest in guaranteeing desired complex behaviors of dynamical systems (e.g., periodically visit region A; first visit region A then visit region B; or if event X happens, then region A should be visited). This course will present recent results on the topic of formal methods for dynamical systems that combine and extend ideas from control theory, dynamical systems, automata theory, logic, and reinforcement learning.

Recommended Textbook(s):

- C. Belta, B. Yordanov, E. Aydin Gol, Formal methods for discrete-time dynamical systems, Vol. 89, Springer, 2017.
- H. Lin and P.J. Antsaklis, Hybrid Dynamical Systems: Fundamentals and Methods, Springer, 2021.
- M. Fisher, An Introduction to Practical Formal Methods Using Temporal Logic, Vol. 82, Wiley, 2011.
- C. Baier and J.P. Katoen, Principles of model checking, MIT press, 2008.

Course Topics

- Models
  - Continuous systems
  - Hybrid systems
  - Transition systems
  - Automata and languages
- Verification
  - Stability and reachability analysis
  - Model checking
- Control synthesis
  - Synthesis with various temporal logics (LTL, TWTL, STL)
  - Implementation of mixed integer linear program, model predictive control, reinforcement learning with temporal logics

Grade Breakdown:

- Coding Assignments + Paper presentations + Final Project

Next time

Nov 22 – Dec 4,6: Reading Week

- Each paper: ~15 min presentation + ~10 min discussion
- Please read the papers before coming to the class.

The week of Dec 9th: Project presentations

- ~20 min presentation + ~10 min Q&A
- Format:
  - Problem statement (scenario definition, problem definition)
  - Proposed approach
  - Results
  - Discussion (challenges faced, observations)