Driver assistance system design A

Introduction to the course

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Outline

Course organization

- Lectures:
  - Theory/methodology.
  - Examples/exercises.
  - Simulations.
  - Teacher: Carlo Novara.
- Lab sessions:
  - Exercises/problems/design.
  - Teachers: Carlo Novara, Michele Pagone.
- Projects:
  - Projects about driving assistance system design in collaboration with Part B.
  - Teachers: several teachers from Parts A and B.
- Use of Matlab/Simulnk in lectures, labs and projects.

Course organization

- Lectures:
  - Presenting new topics/material (theory, examples, simulations).
  - Questions, Answers and Discussions (QAD).
- Lab sessions and projects:
  - Exercises and simulations will be similar to those discussed during the lectures.
  - Students are expected to be prepared for the lab sessions and projects. The level of the proposed exercises is tailored for students that have studied what presented during the lectures.
  - The goal is to teach to students not only technical notions but also to become independent, able in problem solving and creative.
  - Interactive modality: QAD and deepening of the studied topics.

Course organization

	Monday	Tuesday	Wednesday	Thursday	Friday
8,30-10,00					DRIVER ASS. Lab
10,00-11,30					DRIVER ASS. Lab
11,30-13,00			DRIVER ASS. Les.		
13,00-14,30			DRIVER ASS. Les.		
14,30-16,00		DRIVER ASS. Lab		DRIVER ASS. Les.	
16,00-17,30		DRIVER ASS. Lab		DRIVER ASS. Les.	
17,30-19,00					

- The available slots will be used with flexibility.
- Coordination between Part A and Part B.
- Part A: Wednesday and Friday.
- Possible changes will be communicated in advance.

Course overview

- Control is a multi-disciplinary area, involving theoretical, numerical and hardware tools, finalized at modifying and optimizing the behavior of real-world systems.
- Control is nowadays fundamental in most fields of science and technology:
  - automotive, aerospace, robotics and energy, biomedical, data analytics, communications and networks.
- The goal of the course is to present basic and advanced control methods suitable for driver assistance systems and autonomous driving.
  - One part of the course is dedicated to the study of basic and advanced control methods.
  - Another part regards the application of these methods to driver assistance systems.
- Pre-requirements: differential and integral calculus, vector valued functions, linear algebra, basic physics, basic notions on dynamic systems and automatic control, basic notions about Matlab/Simulink.

Course overview

1. Dynamic systems, automatic control, Matlab/Simulink.
   - Dynamic system properties; state equations; stability concepts.
   - Basic notions about feedback control.
2. Basic and advanced control methods (useful for driving assistance systems):
   - PID control, eigenvalue placement.
   - LQR/LQI control, Gain-Scheduling, Model Predictive Control.
   - Observer/filter design for linear and nonlinear systems.
3. Examples of applications to driving assistance systems. Presented during lectures and developed by students in the labs (using simplified models). Topics:
   - lateral and longitudinal control,
   - platoon control,
   - trajectory planning and control.
4. Projects (in collaboration with Part B):
   - Development and analysis of a high-fidelity vehicle model, design of vehicle dynamics control strategies, trajectory planning and control. (Development/use of high-fidelity models).

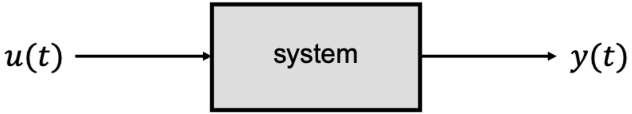
Dynamic systems

A dynamic system can be (roughly) defined as a set of interacting objects which evolve over time.

Examples:

- vehicles
- mechanical systems
- electrical circuits
- aircrafts
- spacecrafts, satellites
- stock market
- animal population
- atmosphere
- planet systems
- and so on...

Dynamic systems

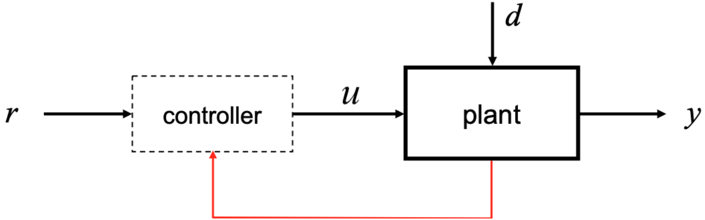


- Fundamental variables:
  - Input $u(t)$: variables which influence the time evolution of the system (causes).
  - Output $y(t)$: measured.

- Input types:
  - Command inputs: their behavior can be chosen by the human user.
  - Disturbances: their behavior is independent on the human user; they cannot be chosen.

What is control?

- Controlling a dynamic system (plant): using a command u such that the corresponding output y tracks a desired reference r.
- The controlled system should be as little as possible sensitive to the disturbance d.



Control design problem: Find a system, called the controller, such that $y \cong r$ for a set of reference signals of interest. $\square$

Control methods

- Time-domain methods:
  - eigenvalue (pole) placement,
  - proportional integrative derivative (PID),
  - optimal control (LQR),
  - model predictive control (MPC),
  - internal model control (IMC),
  - embedded model control (EMC)
  - gain-scheduling,
  - feedback linearization,
  - sliding mode control,
  - etc ...
- Frequency domain methods:
  - pole placement,
  - proportional integrative derivative (PID),
  - root locus,
  - lead-lag compensator,
  - internal model control (IMC),
  - H_∞ control,
  - etc ...

Control methods - PID control

- Proportional Integral Derivative (PID) control is probably the most popular control approach in industrial applications:
  - automotive
  - aerospace
  - electrical systems
  - power systems
  - chemical processes
  - many others ...
- The main reason for such a popularity is its simplicity: a standard PID controller is characterized by a few parameters,
- The PID parameters can be suitably tuned
  - off-line, via computer design and simulation,
  - on-line, directly on the physical plant of interest.

Control methods - state feedback

- State feedback is a fundamental principle for control of linear and nonlinear systems.
- It can be applied to a large class of systems:
  - Nonlinear (without using linearization)
  - Time-varying
  - MIMO.
- It accounts for the connection between the internal and external descriptions.
- It allows to introduce optimality concepts.
- It can deal with constraints on states, input and output.
- It allows a more effective stabilization of unstable complicated systems.
- We'll consider the following approaches:
  - "manual" eigenvalue placement (LTI systems).
  - LQR/LQI optimal design (LTI systems).
  - Gain-scheduling (nonlinear systems)
  - Model Predictive Control (linear and nonlinear systems).

Control methods - MPC

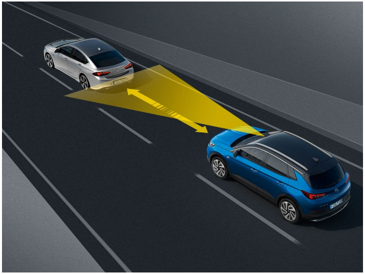
- Model Predictive Control (MPC) is a general and flexible approach to control of linear and nonlinear systems.
- MPC allows us to deal with input/state/output constraints and to manage systematically the trade-off performance/command effort.
- **Approach.** At each time step:
  - A prediction over a given time horizon is performed, using a model of the plant.
  - The command input is chosen as the one yielding the "best" prediction (i.e., the prediction closest to the desired behavior) by means of some on-line optimization algorithm.
- Many industrial applications: automotive systems, aerospace systems, chemical processes, robotics, biomedical devices, etc.

Application: lane keeping

- The goal of lane keeping systems is to maintain the vehicle within the lane through a control action on the steer.
- Indeed, lateral dynamics is unstable and control is necessary to keep the vehicle in the lane (in manual driving, controller = driver).
- The control system is not intended to replace the driver.
- The control system is aimed to improve safety:
  - help the driver in emergency situations, e.g. in the case of tiredness, lack of attention, critical road conditions, etc.
  - reduce the driver's tiredness/drowsiness.

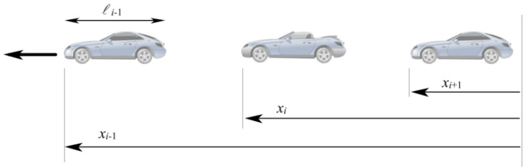
Application: cruise control

- A cruise control system automatically regulates the throttle of a vehicle to maintain a desired speed.
- It is the driver's responsibility to ensure that the vehicle can safely travel at the desired speed on the road.
- If a preceding vehicle travels at a slower speed or is too close to the vehicle, the driver must take action and if necessary apply brakes.
  - Application of the brakes automatically disengages the cruise control system and returns control of the throttle to the driver.



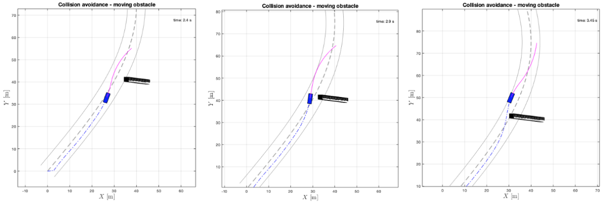
Application: adaptive cruise control

- Adaptive Cruise Control (ACC) is an evolution of standard cruise control, based on a radar or other sensors that measure the distance from the preceding vehicle (PV).
- The goal of ACC is to ensure all the vehicles in the same group (string or platoon) to move at a consensual speed while maintaining the desired spaces between adjacent vehicles.
- Advantages with respect to standard cruise control and "manual" driving:
  - increased traffic capacity,
  - improved safety,
  - improved comfort,
  - reduced fuel consumption.
- Stability properties of the platoon are fundamental.



Application: trajectory planning and control

- Global trajectory planning (path planning): Find an optimal path between two points on a map, avoiding obstacles (and possibly on roads).
- Local trajectory planning: Similar to the global one but:
  - The trajectory is planned over a shorter time interval.
  - The planned trajectory should be consistent with the vehicle dynamics.
  - The trajectory is planned in real-time.
- Trajectory planning and control (TPC): Trajectory planning + providing the control action that makes the vehicle track the planned trajectory.
- TPC can be performed in combination with low-level lateral and longitudinal controllers (lane keeping and cruise control).



Bibliography

1. Lecture material (slides, Matlab/Simulink files).
2. G.F. Franklin, J.D. Powell, A. Emami-Naeini, Feedback Control of Dynamic Systems, Prentice Hall, 2009.
3. Kwakernaak, Huibert & Sivan, Raphael, Linear Optimal Control Systems. Wiley, 1972.
4. J-J. E. Slotine and W. Li, Applied Nonlinear Control, Prentice Hall, 1991.
5. F. Borrelli, A. Bemporad, M. Morari, Predictive control for linear and hybrid systems, Cambridge University Press, 2014.
6. L. Grune and J. Pannek, Nonlinear Model Predictive Control - Theory and Algorithms, Springer, 2011.
7. G. Genta, Motor Vehicle Dynamics, World Scientific, 2002.
8. R. Rajamani, Vehicle Dynamics and Control, Springer, 2012.
9. Preparatory material of automatic control can be found at the website

   https://www.polito.it/didattica/corsi-di-laurea-magistrale/mechatronic-engineering-ingegneria-meccatronica

Exam

- Mandatory:
  - Computer-based written test with multiple-choice and open-ended questions using the Exam platform and Matlab/Simulink.
    - Theory/methodology.
    - Exercises/problems.
    - Simulations.
    - Design.
  - Project report.
- Optional:
  - Oral exam (in particular situations).
- Other technical details will be given at the end of the course.