4F3 - Predictive Control

Lecture 1 - Introduction to Predictive Control

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Constraints in Control

- All physical systems have *constraints*:
  - Physical constraints, e.g. actuator limits
  - Safety constraints, e.g. temperature/pressure limits
  - Performance constraints, e.g. overshoot

- Optimal operating points are often near constraints

- Most control methods address constraints *a posteriori*:
  - Anti-windup methods, trial and error
Optimal Operation and Constraints

Classical Control
- No knowledge of constraints
- Set point far from constraints
- Suboptimal plant operation

Predictive Control
- Constraints included in design
- Set point closer to optimal
- Improved plant operation
Getting closer to constraints

(a)

(b)

(c)

Constraint
The Receding Horizon Principle

![Graph showing the receding horizon principle with set point and constraints.](image)
The Receding Horizon Principle

- **Input**
  - Set point
  - Constraint

- **Output**
  - Time

- **Constraint**
  - Time

At time $k$, the system starts adjusting to reach the set point while ensuring constraints are met.
The Receding Horizon Principle

![Graph showing the Receding Horizon Principle](image)

- **Set point**
- **Output**
- **Input**
- **Constraint**
- **Time**

At time step $k$, the control strategy predicts the output for the next step $k+1$ and applies constraints to ensure the system remains within predefined limits.
The Receding Horizon Principle

Output

Set point

Constraint

Input

Constraint

Time

\( k \)

\( k + 1 \)
Summary of Predictive Control

Receding Horizon Control (RHC) ⇔ Model Predictive Control (MPC)

- At each time instant, a predictive controller:
  1) Takes a measurement of the system state/output
  2) Computes a finite horizon control sequence that
     a) Uses an **internal model** to predict system behavior
     b) Minimizes some **cost function**
     c) Doesn’t violate any **constraints**
  3) Implements the first part of the optimal sequence

- This is a **feedback** control law
Example of MPC: What not How

Pitch angle and constraint

Altitude and set-point

Altitude rate and constraint

Elevator angle and constraint
Properties of MPC technique

- Is this a new idea?
  - No – Standard finite horizon optimal control.
  - Yes – Optimization in the loop, in ‘real time’.

- The main problems:
  - Optimization needs to be fast enough.
  - The resulting control law might not be stable.

- The main advantages:
  - Systematic method for handling constraints.
  - Flexible performance specifications.
  - Easy to understand.
Historically, MPC has been used on ‘slow’ processes:
- Petrochemical and process industries, *pulp and paper*
- Sample time of seconds to hours

Major advances in hardware and algorithms
- Computation of 1 minute in 1990 $\Rightarrow$ now less than 1s

MPC now being proposed for ‘fast’ processes:
- Automotive traction and engine control
- Aerospace applications
- Autonomous vehicles
- Electricity generation and distribution
Also Known As...

Other Names in Industry and Academia:
- Dynamic Matrix Control (DMC)
- Generalised Predictive Control (GPC)

Generic names:
- Model Predictive Control (MPC)
- Model Based Predictive Control (MBPC)
- Receding Horizon Control (RHC)
Books


What is in this course?

In
- Linear systems with constraints
- Linear inequality constraints on states and outputs
- Discrete-time
- Continuous state/input systems
- Ensuring stability with predictive control
- Case study: Paper making

Out
- General nonlinear systems
- Robust predictive control
- Discrete states and hybrid systems
Course Outline

- Introduction to predictive control
- Discrete-time state space control theory — handout only
- Predictive control without constraints
- Predictive control with constraints
- Stability and feasibility in predictive control
- Setpoint tracking and offset-free control
- Industrial case study – Dr Paul Austin – Fri. 5 March
- Examples Class – 2 Examples Papers – Tue. 9 March