Using Open Modelica and OMNotebook for Control System Teaching

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Context

- Energy Engineering MSc programme, Politecnico di Milano
- Course on Automatic Control, 8 credits = 80 class hours
- Students have no previous knowledge in the field
- Main Topics
  - Linear and non-linear dynamical systems
  - Transfer functions
  - Stability
  - PID control system design
  - Control architectures for the energy sector

Course Goals

- Introduce students to system dynamics and feedback concepts (mech./chem. eng. background!)
- Give solid mathematical foundations for classical PID control theory
- Give a broad overview of control applications in the energy sector
- Make the students aware of the importance of system dynamics and feedback control
- Make the students aware of critical issues when dealing with control systems
- Enable students to interact with control system experts in their professional career

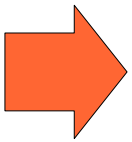
Why using simulation?

- Control system theory is highly abstract
- The theoretical approach can scare off students who don't see the relevance of the theory for the practical applications
- Setting up experimental lab activities is unfeasible (80+ students, little time available)

- Simulation allows students to experiment on their own, at their own pace
  - Verify that theoretical design rules work in practice
  - Perform what-if studies
  - Handle more realistic problems where theory must be used with judgement to solve actual problems
- Zero-cost solution (everyone own a laptop nowadays)

Requirements for simulation software

- Free software
  - Using commercial software for such basic activities is nonsense
- Multi-platform
  - Students use Windows, Linux (and Mac!)
- Easy to use
  - Little time available to learn how to use the tool
- System modelling should be declarative
  - Don't let student even think of using block diagrams for physical modelling!
- Block diagrams ?
  - Useful to understand the structure of control systems
  - Only basic SISO systems covered in the course
- Support for exam assignments
  - Documents including models, simulation and text



OMC / OMNotebook

Analysis of Simple System Dynamics

- Dynamic models of simple systems are presented in the course, e.g.:
  - Tank + valve
  - Water heater
  - Spring-mass
  - Pendulum
- Dynamic behaviour is analyzed using systems theory
  - Linearization
  - Step response
  - Sinusoidal response
- Simulation allows to verify theoretical results, compare system responses, etc.
- First simple examples shown in the lab w/ instructors, others left as homework
- Templates are provided, no prior knowledge of Modelica is required

Live Demo

Water Heater Dynamics

PID Control of a Tank

Final Exam Assignment

- Solve a set of increasingly difficult control problems
- Non-trivial problem specifications with multiple conflicting requirements
  - require understanding of theory
  - and multiple experiments by simulation
- Students should explain how the problem has been solved
- Automatic generation of assignment files
  - takes instructor's file with reference solutions as input
  - assigns unique set of numerical parameters for each student
  - removes solutions
  - implemented as Matlab script (alternatives: Python, Java)

Live Demos

Solved Assignment Document

Empty Assignment Document

File generation script

Feedback

- Very lightweight learning curve: one lab session, then students use it autonomously
- Students get involved with the simulation activity
- Performing what-if simulations reinforces the theoretical concepts and the pencil-and-paper analysis
- Exam assignments carried out satisfactorily by majority of students
- Some assignments show significant originality
- Many students report simulation has helped them understanding the subject better
- Some tool issues with large documents and large simulation result datasets

Conclusions

- Simulation is a key factor for effective teaching of basic Automatic Control courses
- OMNotebook proved more than adequate for the purpose:
  - understanding system dynamics
  - understanding basic control design issues
- OMNotebook also allowed to easily manage exam assignments involving simulation

- Open issues:
  - how to manage modular models (e.g., block diagrams)?
  - is that really necessary for a basic course?