Projects in Adaptive Control 2004

Important Dates

You should have chosen a project and formed a project team before **October 1 1 .**

Requirements

Your project will be accepted if it passes the following requirements:

- A short, 5–10 pages, project **report** (in Swedish or English) should be written. The report should be written with a word processing system. The suggested solution provides a good structure for the project report.
- A few projects will be selected for **oral presentation**. The exact presentation time will be given by the instructor, but it will typically be about 10 minutes. Nice view transparencies should be made.

For projects that are done jointly with the course in real-time systems the following is also required. These projects are market with a * after the number.

- Project participants should organize the work so that real-time project and adaptive control project proceed in parallel. To that purpose, software from the real-time workshops may be re-used.
- A **program** that fulfills the specifications should have been demonstrated for your project supervisor. Each team member should be able to answer questions about the program structure and about why a certain solution has been chosen.
- The project should be **demonstrated** during the second hour of the project presentation lecture.

Standard Projects

These projects are well related to your take home problems. They will give you a good insight into adaptive controllers and their behavior. The outcome is also quite predictable. The projects can be done entirely with pencil and paper and simulations.

Project 1 - Control of an Inverted Pendulum

A simple linearized model of an inverted pendulum is

$$G(s) = \frac{k}{s^2 - b}$$

where the input is acceleration of the pivot, the output is the angle, and k and b are unknown constants. It is difficult to make an adaptive controller for the pendulum because it may fall down during the initial transient. An alternative is to make an adaptive controller for the pendulum in the downward position. The model is then

$$G(s) = \frac{k}{s^2 + b} \tag{1}$$

Let the adaptive controller tune with the pendulum in the downward position until a good performance is obtained. Use this controller to compute a controller for the upward position. Show that your proposed scheme work by simulating the system obtained.

You can design the controller based on the specifications that the closed loop response should be given by

$$G_m(s) = \frac{a^2}{s^2 + 2\zeta as + a^2}$$

Base the controller of estimation of the parameters of the model

$$H(z) = \frac{b_1 z + b_2}{z^2 + a_1 z + a_2}$$

which has four parameters. The problem is closely related to the problems you have already done. Use the previous results and the model parameters you used in the homework problems. Simulate your system using the real nonlinar model.

Project 2 - Control of an Inverted Pendulum

Same as project 1 but base the estimation on a continuous time system with only two parameters k and b of the model (1). The continuous time model should be sampled and a discrete time design should be used. Simulate your system using the real nonlinar model.

Project 2' - Control of an Inverted Pendulum

Compare the approaches used in projects 1 and 2. You can use material from previous projects for this.

Adaptive Control of Laboratory Processes

These projects are all done jointly with the course in real-time systems. The idea is to try adaptive control on a laboratory process. This is more complicated than to simulate but it gives a much better appreciation of real engineering issues in implementation of adaptive controllers. There are toolboxes and program libraries for control design and estimation which you can use.

Project 3* - Mass-Spring-Damper System

A mass-spring-damper system arranged for linear acceleration is available in our laboratory. Apply adaptive control for improved damping of oscillation modes.

Project 4* - Control of an Inverted Pendulum

Same as Project 1 but implement the system in a real-time environment and try it out on the real pendulum.

Project 5* - Control of an Inverted Pendulum

Same as Project 2 but implement the system in a real-time environment and try it out on the real pendulum. Approximate the continuous time controller by sampling fast and run the parameter estimator at a slower sampling rate.

Project 6* - Adaptive Control of the See-saw Process

Try indirect adaptive control of the see-saw process.

Project 7* - Control of the Helicopter Model with Gain Scheduling

Try gain scheduling control on the helicopter process.

Project 9* - Adaptive Friction Compensation

Consider a controller that stabilizes an inverted pendulum. A simple model of friction leads to a piece-wise linear systems for which the standard adaptive techniques apply. Implement an adaptive friction compensator and explore its properties.This project can be expanded to a Masters thesis.

Real-time Software for Adaptive Control

These projects are all done jointly with the course in real-time systems. The idea is to develop real-time software that can be used for adaptive control.

Project 10* - PID Control with Automatic Tuning

Implement a PID controller with automatic tuning. Use an experimental method which admits determination of at least three parameters. Use the new tuning formulas developed by KJ and Tore. See Åström and Hägglund PID Controllers - Design, Implementation and Tuning, ISA 1995. The auto-tuner contains a mixture of control and logic. Special attention should be given to good structuring of the algorithms. The system should admit several different control design methods and relay experiments in open or closed loop with and without extra filters. This project can be expanded to a Masters thesis.

Project 11* - Man-machine Interface for an Auto-tuner

Implement a good man-machine interface for an auto-tuner in InTouch. The interface should be easy to use for an inexperienced user and it should allow much freedom to an experienced user. It should allow a variety of experiments, for example steps and relay feedback. Several different design methods should be incorporated. The system should also allow on-line validation of a design. This project can be expanded to a Masters thesis possible with a Java implementation.

Project 12* - An Indirect Adaptive RST controller

Implement a good indirect self-tuner in our real-time environment on an IBM PC. The system should be tested on our process simulator. The system should be capable of running in several modes, manual, automatic with fixed controller parameters, automatic with parameter estimation and adaptive. It should be possible to run the estimator at a lower priority or at a lower sampling rate. Parameter estimations could thus occur at irregular simes. Attention should also given to sound numerics. There are some base libraries that can be used. This project can be expanded to a Masters thesis possible with a Java implementation.

Project 13* - Man-machine Interface for a Direct Adaptive Controller*

Implement a good man-machine interface for a direct adaptive controller. Pay special attention to the structuring of the interface so that it is easy to use for inexperienced users and that it allows a sophisticated user full freedom. The interface should be implemented in InTouch. This project can be expanded to a Masters thesis possible with a Java implementation.

Project 14* - Automatic Initialization of an Adaptive Controller

Use a auto-tuner to initialize an indirect adaptive controller. By using an experiment with relay feedback it is possible to obtain information about suitable sampling rates and reasonable specifications on the closed loop system. This project can preferably be done in collaboration with other projects. Results from earlier projects can also be used.

Simulation of Adaptive Controllers

There are several simulation tools that can be used to simulated adaptive controllers. Simulink is a traditional simulator connected to Matlab. Dymola and Omola are two simulators that are based on much more advanced concepts. Dymola was developed in a PhD thesis by Hilding Elmqvist. Hilding (PhD #15 from the Department of Automatic Control at LTH), now has a company Dynasim in the Science Park that develops simulation tools. Dymola runs on a PC and has superb facilities for animation. Omola-OmSim is an object oriented modeling and simulation environment that has been developed by Sven-Erik Mattson (PhD #26) and Mats Andersson (PhD #43) which runs on workstations. With these tools it is possible to structure the simulations and to write quite elegant code. The idea with these projects is to develop libraries for adaptive control that can be used in future courses. It is also interesting to compare the ease of use of the different simulation environments.

Project 16 - Indirect Adaptive Control in Modelica/Dymola

Write a toolbox for simulation of a direct self-tuning controller. Think about a suitable structure which is pedagogic and easy to use. Verify the program by applying it to Examples 3.4 and 3.5 in the book and Homework 1. This project can be expanded to a Masters thesis.

Project 17 - Simulation of Effects of Initial Conditions

Use the Simulink toolbox for indirect adaptive control and develop an educational sequence that illustrates the choice of initial conditions in the parameter estimator. You can experiment with different intial values as well as different excitation. You may have to extend the model library. Use the standard cases in the book as illustrations. This project can be expanded to a Masters thesis.

Project 18 - Simulation of Effects of Forgetting

Expand the Simulink toolbox for indirect adaptive control so that it can deal with different schemes for forgetting. Develop some experiments that illustrates the properties of the different forgetting schemes. This project can be expanded to a Masters thesis.

Project 19 – Control of Dissolved Oxygen Level

This project treats control of dissolved oxygen in a bioreactor where the oxygen supply is manipulated using the stirrer speed. In batch and fed-batch cultivations the operating conditions change significantly which may cause tuning problems if a fixed controller is used. Investigate how a control strategy based on PID control and gain scheduling can be used to account for the process variations. An approximate process model is available. A possible alternative is to develop a simple adaptive controller for the process. This project can be extended to a Master's thesis.

Project 20 – Extremum Control

For some processes it is difficult to find the best operating point or a suitable reference value. A classical example is control of air-fuel ratio in combustion motors where the optimum depends on temperature, fuel quality, etc. One would then like to have a way to find and track the optimum operating point. This kind of problem is often referred to as extremum control. The topic of this project is to study extremum control of two simple processes. One where the non-linearity is of on-off-character, as in a lambda sensor, and one where the non-linearity is of saturation type.

Theoretically Oriented Projects

The following projects have a theoretic flavor. The first project is of interest for those who are studying nonlinear dynamics.

Project 21 - Chaotic Behavior of Adaptive Systems

Adaptive systems may have chaotic behavior. Verify this by investigating the simple adaptive system discussed in Section 6.2 in the textbook. Investigate the properties of the system in the boundary of the stability region in Fig. 6.1. In particular explore what happend at the corners of the stability region. Look for period doubling and explore the nature of the attractors. This project can be expanded to a Masters thesis.

Project 22 -Nonlinear Dynamics and Adaptive Control

Consider the system described by the differential equation

$$\frac{d^2x}{dt^2} + (a - x)\frac{dx}{dt} + x(x^2 - 3x + 2) = u$$

Mathematics Part Let the control signal be zero. Let the parameter a have the nominal value 3. Explore the differential equation obtained. Determine equilibrium points and their character. Investigate if there are periodic solution. Determine the phase plane. Explore how the nature of the equilibria changes with the parameter a.

Control Part Determine an indirect self-tuning adaptive controller that gives a closed loop system characterized by

$$\frac{d^2x}{dt^2} + \frac{dx}{dt} + x = u_c$$

Investigate how the system behaves when the command signal is

$$u_c(t) = vt + b\sin t$$

Investigate the behavior for different values of v. Explain what happens analytically?

Project 23 - Literature Study

Pick some section of the book that you find interesting and study the proofs in full detail complemented by literature studies.

Project 24 - Literature Study

Read a paper on adaptive control in IEEE Transaction on Automatic Control or Automatica. Try to understand the article and verify it by simulation. We will help you to select a good paper.

Project 25 - Nonlinear Adaptive Control

There are recent results on adaptive control of nonlinear systems. See e.g. Section 5.10. Study some of this mehtods and apply them to a simple case.

Project 26 - The Phenomenon of Peaking

There is a phenomenon called "peaking" which means that an adaptive controller may have a large initial transient. It is claimed that some of the new nonlinear methods give less peaking. Study this and try to understand what happens. This project can be expanded to a Masters thesis.

Project 27 - PI Adjustments

Investigate the MRAS with PI adjustment of parameters. Show that this is very similar to one of the nonlinear control schemes.

Project 28 - Your Own Ideas

If you have your own idea about a project please feel free to come and discuss it, but please remember that the project should be no longer than a week.

1996 K. J. Åström/ Revised 1998, 1999, 2000 R. Johansson