Problems in advanced adaptive control teaching in engineering education

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Abstract

The paper concerns the results from teaching advanced process adaptive control and identification topics at large Electrical Engineering faculty, Silesian University of Technology, Poland. The author of the paper is involved in the above mentioned course with respect to lectures, supervising project work and consulting the laboratory exercises setup and running. Some interesting results related to engineering students' work were also obtained while supervising final year projects by the author.

Introduction

In the paper some experience concerning teaching advanced adaptive control and identification at large electrical engineering faculty is reported. The course on adaptive control includes all typical elements of teaching like lectures, laboratory exercises, project work, problem solving and working on final year project.

The specific process adaptive control topic discussed in the paper concerns the discrete time representation of process model while designing the adaptive control system – including identification part. In order to work with mentioned problem students have to use their knowledge from such fields as systems theory, process dynamics, control theory and other. Specific problems concern the choice of structure of the discrete time model – especially using the reduced order structure, as well as the choice of model from the parameter estimation point of view – including possible enhancement in the form of using two estimation procedures, in parallel but with different time scales, with subsequent filtering.

In the paper the above mentioned phenomena are presented together with discussion concerning the understanding of these topics by students and methodologies and tools that can enhance such understanding.

Adaptive control course contents

In this section the contents of the analyzed adaptive control course is described, together with pointing out topics and areas that can cause problems in understanding by students and implementing in the simulation software as well as while designing the real world examples of control system.

The course on adaptive control considered in this paper includes an introductory part topics like process control system tuning and adaptive control system classification [1,2]. The students explore also some basic groups of adaptive control schemes including model reference adaptive control systems, adaptive control systems with programmed changes of the controller parameters (so called gain scheduling) and adaptive control systems with system model identification.

Stability and minimum-phase properties of the adaptive control system plant are also discussed, together with stability, convergence and robustness related requirements in the adaptive control system. It is well observed that students are usually aware of control system instability problem, however, they do not understand well the non-minimumphase behavior problem. Direct and indirect adaptive control systems are also defined and analyzed as well as transfer function and predictive model of the plant in adaptive system. Identification and parameter estimation in adaptive control systems are analyzed with transfer function and predictive model identification options.

Advanced adaptive control course has to include the modeling and analysis of impact of controlled plant environment on the plant properties and performance. Usually such effects are modeled by means of additional input channels – in simpler cases of deterministic characteristics and in more complex – of stochastic nature. The lecture includes also stochastic models of disturbances in adaptive control systems as well as simpler deterministic disturbances, including representation of disturbances, disturbance models, disturbance types and rejection possibilities.

Students working on adaptive control and identification courses are warned that there are not many properties and theorems related to such systems behavior that can be proved by means of theoretic tools and methods. Consequently, several important properties of adaptive control systems have to be examined by means of simulation. The lecture includes therefore several topics related to dynamic system simulation, including the setup of simulation experiment as a tool for adaptive control system analysis and synthesis. Adaptive control system performance indices evaluation are proposed and compared.

One of the main parts of the adaptive control lecture concerns the control algorithms used in adaptive control systems. The students are presented with pole placement adaptive control systems, pole-zero placement adaptive control systems, consider model reference adaptive systems and explore various versions of adaptive minimum variance control systems. The other adaptive control algorithms discussed during lecture include long range predictive adaptive systems, MAC and GPC examples of predictive control algorithms, adaptive control systems based on step and pulse responses of the plant and auto-tuning and adaptive versions of PID controllers.

Majority of adaptive control algorithms covered in the advanced adaptive control courses are of Model Identification adaptive control type, i.e., they include usually advanced identification and estimation algorithms and procedures – which have to be included in the course contents. The topics include recursive estimation algorithms in adaptive control systems, forgetting factor choice in recursive estimation schemes, numerical properties of recursive estimation algorithms, stability of adaptive control systems with various estimation schemes, as well as convergence of recursive estimation algorithms in adaptive systems.

The Adaptive Control course optionally include lectures and exercises on continuous time model based adaptive control systems, fuzzy logic based design and synthesis of control systems, fuzzy adaptive control design schemes and applications, evolutionary optimization algorithms as tools for identification and choice of structure in adaptive control systems and multivariable adaptive control systems – multivariable models of control system plant and multivariable plant model identification.

The specific process adaptive control topic discussed in the paper concerns the discrete time representation of process model while designing the adaptive control system – including identification part. In order to work with mentioned problem students have to use their knowledge from such fields as systems theory, process dynamics, control theory and other. Specific problems concern the choice of structure of the discrete time model such as using the reduced order structure, choice of model from the quality of parameter estimation point of view, as well as using two estimation procedures with different time scales and regression variables filtering.

Problems in advanced adaptive control teaching

In this section some advanced phenomena of both theoretical and implementation related nature, characteristic for the adaptive control system operation, are discussed.

To begin with, the main objective of the adaptive control course is to provide the students with basic and advanced knowledge concerning theory, analysis and synthesis of adaptive control systems. During the course the students should develop the skills concerning the methods of theoretical analysis and synthesis of adaptive control systems as well as the skills of building and using computer simulation packages for analysis of such complicated control systems behavior.

It is generally agreed that analysis and synthesis of adaptive control systems is a difficult task [3]. Usually engineers decide to implement adaptive control when the controlled plant or its environment is nonstationary, which also means that it is very difficult to analyze from the control theory point of view. The nonlinearity of the controlled plant and set-point changes, which is rather typical for control systems, is other possible reason for building adaptive control system, which again is difficult for analysis and synthesis because of nonlinearity.

One of the most important and difficult elements of adaptive control system is its nonlinearity, which is simply inherent due to the nature of such systems. Students are thoroughly taught to understand that in adaptive control system there are two groups of changing elements – signal values and controller parameters, and because these elements appear in products in almost all models of such systems, this makes such systems inherently nonlinear, i.e. difficult for analysis from the control theory point of view. It should be also remembered that there is an important duality in adaptive control systems with respect to control task and corresponding performance index and the identification task with its own performance index. The two tasks and indices are not separate and it is not easy to solve them both at the same time.

Of course during the analysis and synthesis of adaptive control system with identification and estimation it is typical to assume vastly simplified structure and behavior of such systems. The students are taught that almost all major types of adaptive control systems use so called stochastic equivalence principle, which means that in many implementations the results of estimation procedures are used for controller design as deterministic parameters, i.e., there is separation between estimation and control procedures. Such assumption is almost natural, however, it incorporates absolutely fundamental simplification to the adaptive control system. It is also customary to model the controlled plant by means of simplified dynamical model – taking into consideration only basic dynamical phenomena. In fact it is a very good topic of laboratory exercise and project work – to simulate more reach dynamical model of the controlled plant and to use simplified model for identification and adaptive control algorithm synthesis. The importance and usefulness of simulation methods for the synthesis of adaptive control systems and analysis of its properties are invaluable. It seems especially reasonable to use control system simulation tools for adaptive control systems as we lack clear and sure procedures for adjusting adaptive control schemes parameters and criteria that would guarantee stability of such systems and convergence of estimated parameters. This means that engineers implementing adaptive control systems and students attending the adaptive control course should be accustomed to the dynamic systems simulation problem and software used for this task.

Control system simulation, both in the continuous time and discrete time domains, is a difficult task and should include very careful choice of numerical methods, programming languages and software development platforms. The identification and estimation algorithms used in the adaptive control systems are also complicated pieces of software that have to provide the rest of the system with the best possible estimates of model parameters very fast and with the best possible numerical properties.

Adaptive control systems are frequently implemented and simulated in the form of discrete time systems. In many cases it may be advantageous to use in such case as small sampling interval as possible. It is well known [3] that too small sampling interval may cause problems in real adaptive control system implementation but also during simulation, therefore special transforms and models are sometimes used and such aspects should be also included in the possibilities of programming language and platform choice.

Other problem present in the typical adaptive control system synthesis of model identification type is that sometimes it could be vital to use direct adaptive control scheme – as it should be definitely faster than indirect adaptive control. However, in several cases the parameter estimation in direct adaptive control suffers from controlled plant dynamics appearing as common factor in the estimated parameters sets. Students attending the adaptive control and identification course are taught to be aware of this problem, to understand its numerical nature and to know the concepts and properties of possible workaround schemes. One of the especially effective methods of coping with this problem is to maintain simultaneously two different models of the controlled plant and to use the simple one for slow rate estimation of auxiliary system dynamics – which enables undisturbed estimation of controller parameters with main plant model, without common factors.

Practical analysis and synthesis of adaptive control systems within AC course

In this section some information concerning the contents and scope of laboratory exercises, project work as well as problem solving, within the structure of the adaptive control and identification course, are reported.

The laboratory exercises and simplified project work within adaptive control and identification course typically consist of programming work on the following group of topics:

- choice of structure of adaptive control systems, sampling period, measurement devices and actuators representation in simulation experiments;
- comparison of adaptive predictive control algorithms, minimum variance control algorithms and pole/zero placement controllers;
- choice of structure and parameters in adaptive control systems with open loop unstable and/or non-minimum-phase plants; these topics include among other the choice of plant model order and verification of possibility of use of simplified plant model without degrading too much the performance of the adaptive control system;
- numerical properties of recursive estimation algorithms in adaptive control systems; within this block of activities students are supposed to implement and test several enhanced and more robust methods for parameter estimation, including various forms of constant trace methods, directional forgetting and automatic adjustment of forgetting factor value;
- synthesis of adaptive control system for nonstationary plant with typical static nonlinearities – comparison of control results for various estimation algorithms and parameters;
- advanced MATLAB/Simulink based design and simulation of adaptive control systems;
- two-scale and two-model estimation of controlled plant/controller parameters – especially useful for direct adaptive control schemes as explained above.

It is clear that laboratory exercises, project work and problem solving tasks accompanying adaptive control course lectures need a lot of nontrivial programming from students.

Conclusions

The adaptive control and identification course topics discussed in this paper concern a great many of adaptive control systems features, with special emphasis on the discrete time representation of process model while designing the adaptive control system – including identification part. The course on adaptive control described in this paper is relatively advanced and difficult for students – it demands from students to use their knowledge from such difficult and diversified fields as systems theory, process dynamics, control theory and other. Specific problems concern the choice of structure of the discrete time model as well as using two estimation procedures with different time scales and filtering.

In the paper the contents of full spectrum advanced adaptive control and identification course was reported and analyzed, together with some specific design problems. It was justified that teaching advanced adaptive control and identification needs careful composing of all course components and very good students' background.

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