WORKSHOP AT THE 2011 IEEE CONFERENCE ON DECISION AND CONTROL

On December 11, 2011, Tansel Yucelen (Missouri S&T), Anthony Calise (GaTech), Eric Johnson (GaTech), and Girish Chowdhary (Oklahoma State) organized a workshop entitled "**Recent Advanced in Model Reference Adaptive Control: Theory and Applications**" at the 2011 IEEE Conference on Decision and Control. Below you will find this workshop's summary, detailed outline, and evaluation via attendees' handwritten comments. Please let Dr. Yucelen know by e-mail if you need a copy of our presentations and/or simulation files that we used in our talks.

Summary

Research in adaptive control theory is motivated by the presence of uncertainties. Uncertainties in real-world systems are inevitable and may be a result of modeling inaccuracies, external disturbances, actuator failures, or airframe damage. Adaptive control is also motived by the desire to reduce control system development time and cost for systems that undergo frequent evolutionary design changes, or that have multiple configurations or environments in which they are operated. This workshop is intended for those who want to receive an introduction to adaptive control as well as those who wish to find out more about some of the latest developments in adaptive control. The workshop will leverage the research experience of the presenters in both theory and practice of adaptive control and provide participants with software examples and other learning resources.

Beginning with a brief review of nonlinear stability theory, this workshop will present a review of a number of well-established methods in Model Reference Adaptive Control (MRAC), a leading methodology in adaptive control. Both linear and nonlinear MRAC formulations will be discussed along with a discussion of robustness of MRAC approaches. Classical MRAC modifications, including sigma-mod, e-mod, and projection based modifications will be discussed. The concept of persistency of excitation will be explored through the study of online parameter identification problems. Participants will have the opportunity to use provided software to simulate MRAC design and analysis.

The workshop will then continue on to discuss the successes and lessons learned of successful implementations of MRAC to real-world systems, including unmanned aerial systems. Methods for adaptation in presence of actuator saturation and sensor noise will be discussed. The workshop will also introduce recent developments in adaptive loop recovery approach that allows the approximate retention of reference model loop properties such as relative stability margins and allows the adaptive controller to mitigate effects of time-delays. It will be shown how the notion of Kalman filtering can be used to update adaptation gains to meet a given performance criteria without excessive tuning.

Several recent advances in MRAC will also be discussed. These include the novel concurrent learning adaptive control and derivative-free adaptive control approaches. Concurrent learning is a memory-enabled adaptive control method that uses online selected and recorded data concurrently

with instantaneous measurements for adaptation. Concurrent learning guarantees exponential tracking error as well as parameter error convergence for a class of adaptive control problems if the system states are exciting over a finite interval, persistency of excitation is not required. Derivative-free adaptive control is particularly well suited for systems with sudden (and possibly discontinuous) change in uncertain dynamics, such as those induced through reconfiguration, payload deployment, docking, or structural damage. It provides superior adaptation and disturbance rejection properties, and computable transient and steady-state performance bounds. Finally the connections between machine learning and adaptive control will be explored in the framework of neuroadaptive control.

Outline

1) Motivation and goals (Tansel Yucelen)
1.1) Discrepancies between real-world systems and their mathematical models
1.2) Adaptive controllers versus robust controllers
1.3) Classification of adaptive controllers

2) Model reference adaptive control (Tansel Yucelen)
2.1) Basic concepts
2.2) Problem formulation
2.3) Derivation of adaptive control laws using Lyapunov's theory
2.4) Stability analysis and worst-case performance bounds

3) Modifications to model reference adaptive control (Tansel Yucelen)
3.1) Structured and unstructured uncertainties
3.2) Classical modifications: sigma-modification, e-modification, and projection operator
3.3) Robustness modification: Adaptive loop transfer recovery (Presented by Tansel Yucelen on behalf of Anthony Calise)
3.4) Construction of modifications using Kalman filter optimization

4) Approximate model inversion-based model reference adaptive control (Girish Chowdhary)
4.1) Adaptive control formulation for general nonlinear systems
4.2) Selection of approximate inversion model and examples

5) Neural networks and neuroadaptive control (Girish Chowdhary)
5.1) Neural networks as general nonlinear function approximators
5.2) Neural networks as adaptive elements in model reference adaptive control
5.3) Making a connection between machine learning and neuroadaptive control

6) Concurrent learning adaptive control (Girish Chowdhary)
6.1) Using online recorded data concurrently with current data to guarantee performance
6.2) Online selection of data to guarantee exponential stability
6.3) Flight test results of concurrent learning adaptive controllers on rotorcraft and airplanes

7) Derivative-free adaptive control (Tansel Yucelen)
7.1) An uncertainty parameterization for fast adaptation
7.2) Derivative-free adaptive control formulation
7.3) Stability based on Lyapunov-Krasovskii functional
7.4) Guaranteed transient and steady-state performance bounds
7.5) Flight control simulation and flight test results

8) Adaptation in the presence of actuator dynamics and saturation (Eric Johnson)
8.1) Pseudo control hedging: A method to handle actuator saturation in model reference adaptive control
8.2) Flight test results of adaptive controllers in the presence of actuator saturations

9) Adaptive control of systems in cascade with saturation (Presented by Eric Johnson on behalf of Suresh Kannan)
9.1) Formulation of cascade problems with an adaptive element
9.2) Nonlinear reference models
9.3) Application of inner-outer loop (cascade) architectures to flight vehicles
9.4) Flight test results on an helicopter, ducted fan, and fixed-wing aircraft

Attendees' Handwritten Comments

We asked our attendees to provide their feedback after our workshop was over, and due to this fact we could only able to collect six handwritten comments given below. Nevertheless, these comments still provide a very useful feedback for us.

Very good workshop.
Nice talking and very informative

Likes

- The pace was just right... I came with a very basic knowledge of adaptive control but I managed to follow basically all the theory.
- The use of many examples and MATLAB coded examples was very helpful to get intuitive insights.

Dislikes

- hmm...not really

Like:

- Taking the audience with you smoothly at the morning
- Offering software, but putting the spot on the methods

Dislike:

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Usage:

- Updating course materials at home university
- Compete with robust control approaches (as H_∞) in practical applications

- Great idea to provide software. Definitely useful !

- Would be useful to provide some basic bibliography before workshop, especially for non-experts

Good:

well-organized presentation with illustrative simulation
provide simulation files for further using (very good !!)
provide related papers

Need to improve:

The last two parts (saturation method and cascaded system) seems not related with the rest of presentation.

- I did like introducing the topic in a very easy way and covering the state-of-the-art in the topic

- I ~~am~~ hoped if there was more general background.

finall thank you.