Adaptive Control

Adaptive Control, a thirty-year old field, is an advanced control method that is becoming increasingly popular in various engineering applications. The ability to self-correct a controller in the presence of uncertainties using online information is its main and most compelling feature. This course will lay out the foundation of adaptive control in continuous-time and discrete-time systems. Examples from aerospace, propulsion, automotive, and energy systems will be used to elucidate the underlying concepts.

The midterm will be assigned towards the end of March, and will be an open book exam.

Grade distribution: Homework: 20%; Midterm: 40%; Project: 40%


Additional notes will be distributed throughout the semester.

Daily class notes will be available at: [http://aaclab.mit.edu/material.php](http://aaclab.mit.edu/material.php)

(aanna@mit.edu)
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Definition of Adaptation

**Biology:** Advantageous Conformation of an Organism to Changes
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Truxal: An adaptive system is one designed from an adaptive viewpoint.
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**Other Definitions:**
Truxal: An adaptive system is one designed from an adaptive viewpoint.

Zadeh: $A$ is adaptive with respect to $S_{\gamma}$ and $\Gamma$ if it performs acceptably well for every source in the family $S_{\gamma}, \gamma \in \Gamma$
Definition of Adaptation (contd.)

**Bellman:**

*Deterministic System:* When the controller has complete information about the behavior of the inputs, and the system is completely specified.

*Stochastic system:* When unknown factors are present in the system which appear mathematically as random variables with known distribution functions

*Adaptive system:* Even less is known about the system and the controller has to learn to improve its performance through the observation of the outputs of the system as it evolves.
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**In this course:**
Adaptive Control: The control of plants with unknown parameters
Control System

- Open-loop Dynamic System

\[ \gamma_{cmd} \rightarrow \text{Plant} \rightarrow y \]
Control System

- Open-loop Dynamic System
- Feedback Control System

Performance Measures: Stability, speed, accuracy
Adaptive Control System

In the presence of uncertainties, using prior and on-line information, the controller adapts itself.
History

Adaptive systems

- Caught the imagination in the 60's
- Several symposia - to define adaptation
- First use in flight control
- Hypersonics program - highly successful
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Adaptive systems

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Five classes of adaptive systems

- Passive Adaptation
- Input Signal Adaptation
- System variable adaptation
- System characteristic adaptation
- Extremum adaptation
Adaptive Control: A Parametric Framework

- Nonlinear, time-varying, with unknown parameter $\theta$
  \[
  \dot{x} = f(x, u, \theta, t) \quad y = h(x, u, \theta, t)
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  \dot{x} = A(\theta, t)x + B(\theta, t)u \quad y = C(\theta, t)x + D(\theta, t)u
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Adapt to the unknown parameter
Direct and Indirect Adaptive Control

θₚ: Plant parameter - unknown;  θᶜ: Control parameter

Indirect Adaptive Control: Estimate θₚ as $\hat{\theta}_p$. Compute $\hat{\theta}_c$ using $\hat{\theta}_p$.
Also known as Explicit Estimation

Direct Adaptive Control: Directly estimate θᶜ as $\hat{\theta}_c$. Compute the plant estimate $\hat{\theta}_p$ using $\hat{\theta}_c$.
Also known as Implicit Estimation
Parametric Adaptation

- Parameter perturbation methods
- Sensitivity methods
In this course

Many of our discussions will involve

Control designs motivated by linear design methods
Parametrizations of the control structure
Parameter adjustment rules - Adaptive laws

What to measure?
What to adjust? How many parameters?
How often?
How do we adjust?

A Stability Framework
In this course

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