Advanced Control Engineering 428

Lecture 1 – Course outline & Overview

Dr. Roshun Paurobally

School of Mechanical Engineering
The University of Western Australia

In Control & Mechatronics 322

- classical control theory and its applications
    - single-input/single-output (SISO)
    - robot arm, active ear defender
- linear control systems
    - described by linear O.D.E, Laplace transform
    - obeys principle of superposition
- stability of feedback control systems
    - consequences of instability
- frequency domain method of analysis and design
    - time domain design requires accurate model
    - frequency domain use experimental data also

In Advanced Control Engineering 428

Aims are to:

- apply advanced methods of analysis and control to dynamical systems
- explain and implement digital adaptive control
- describe modern control techniques and use these to solve control problems
- analyse optimal control techniques and apply them
- Describe and explain non-linear control methods

Contact Hours

36 Lectures

Dr. R. Paurobally – 12 lectures

(1) Adaptive control
(2) Introduction to Modern control

Dr. P. Podsiadlo – 12 lectures

(1) Optimal control

Dr. KD. Do – 12 lectures

(1) Non-linear control

12 Tutorials

2 Labs

(1) Adaptive feedforward control
(2) nonlinear control

Unit Co-ordinator

Dr. Roshun Paurobally

Recommended reading:

(1) Advanced Control Engineering Lecture Notes
R. Paurobally & J. Pan, 2004 – Fiz reserve

(2) Modern Control Engineering, K. Ogata, 2002

(3) Active control of Sound, P. Nelson & S. Elliot, 1992

(4) Nonlinear systems, H. Khalil, 2002

Internet resources

lecture presentations available at:

http://www.mech.edu.au/courses/ACE428

Login : ace428

Password : nofail

Assessment:

Examination (3 hrs)	60%	Nov. 2004 (open book)
2 Labs	10%	to be advised
3 small projects	30%	within 2 weeks

Scaling:

http://www.ecm.uwa.edu.au/for/staff/pol/assess

Penalties:

The assignments and laboratory reports will receive a 1% penalty for each day late. Plagiarism will be dealt with according to Faculty Policy. See **http://www.ecm.uwa.edu.au/for/staff/pol/plagiarism**

Appeals:

http://www.ecm.uwa.edu.au/for/staff/pol/exam_appeals

Course content:

(1) Digital adaptive control

- Sampled data, FIR, IIR filter
- Adaptive filters, gradient methods, LMS
- Adaptive control, FX-LMS

- Used when system characteristics continuously change
- Controller has to be adapted in real time

(2) Modern control

- state-space representation
- observability, controllability
- state feedback, output feedback
- state observers

- Used in systems with multiple-inputs/multiple-outputs, based on states
- can be applied to nonlinear systems and is mainly a time-domain approach

(3) Optimal control

- LQ problems: optimal regulator, finite and infinite horizon control
- LQG problems: Kalman filter, finite and infinite horizon control

- used to minimise some cost function or performance index
- allows constraints to be included such as output power

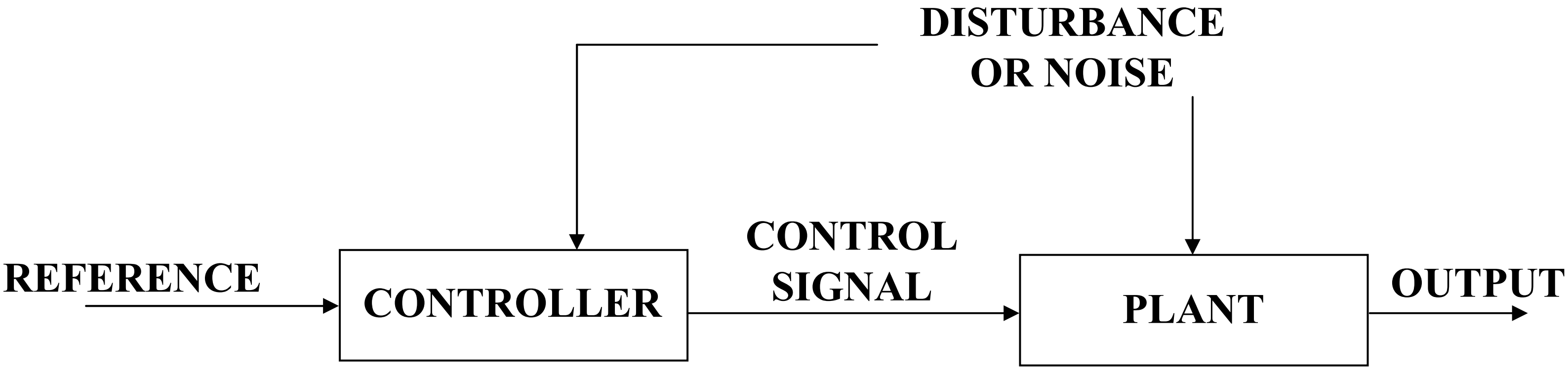
(4) Nonlinear control

- Fundamentals of nonlinear system modeling
- input-output stability, input-to-state stability
- Lyapunov stability
- feedback linearisation, sliding-mode control
- Lyapunov redesign, backstepping design

- used when nonlinear system behaviour cannot be ignored

Adaptive control – Introduction

Consider general feedforward control system- input of controller does not depend on output of plant



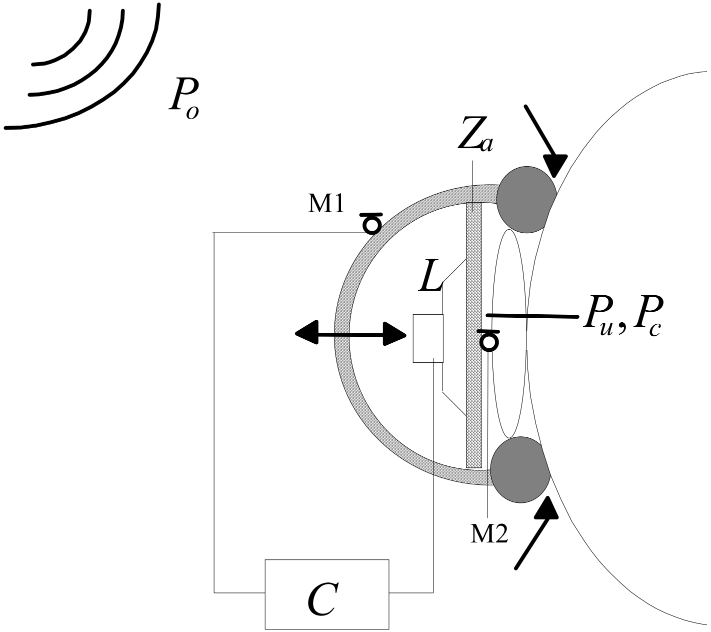
ADVANTAGES

- generally cheaper to build and run (analogue)
- stability is not a problem (open-loop)

DISADVANTAGES

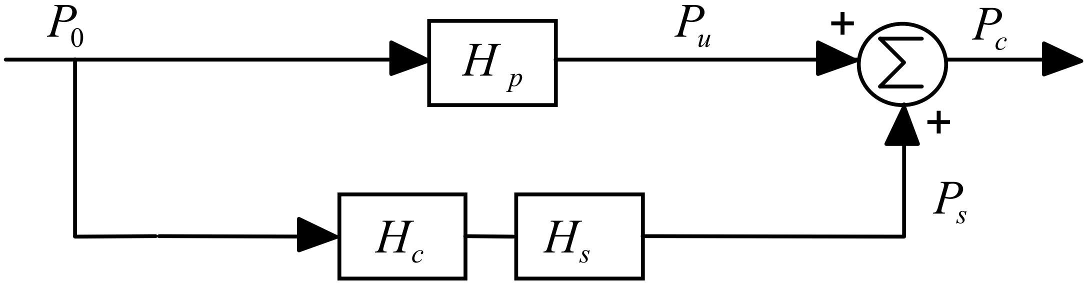
- disturbances must be known or measured
- cannot compensate for internal changes in plant

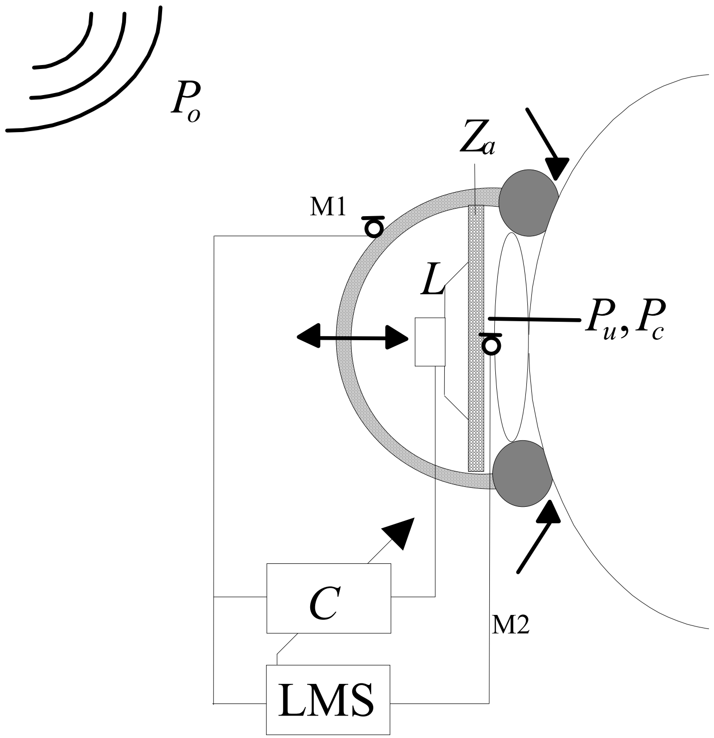
Example – the need for adaptive control



Schematic of a feedforward control ear defender.

$$H_c = -\frac{H_p}{H_s}$$

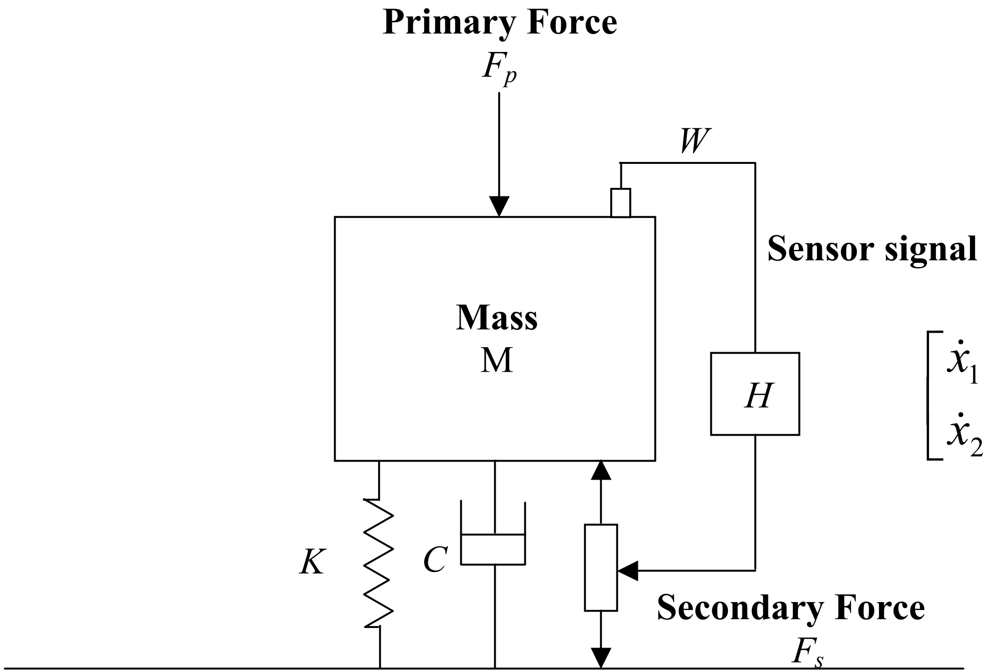




Schematic of an adaptive feedforward control ear defender

- digital controller with coefficients updated in real time
- need to convert analogue signals to discrete signals

Modern control



Define state variables

$x_1(t) = w(t) = displacement$

$x_2(t) = \dot{w}(t) = velocity$

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\dfrac{K}{M} & -\dfrac{C}{M} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ \dfrac{1}{M} \end{bmatrix} f(t)$$

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t)$$

$$\mathbf{y}(t) = \mathbf{C}\mathbf{x}(t) + \mathbf{D}\mathbf{u}(t)$$

ADVANTAGES

- no need to transform to Laplace domain
- elegant method, matrix manipulation easy
- can determine stability, controllability, observability
- can easily extend to multi-input/multi-output systems

DISADVANTAGES

- practical implementation issues, good model needed

Optimal control

Method to design feedback controller to achieve optimum result

Minimisation of a cost function is necessary – proportional to response of system

Usually choose a quadratic cost function such as

$$J = \int_{0}^{t_f} \left[\mathbf{y}^T(t)\mathbf{Q}\mathbf{y}(t) + \mathbf{u}^T(t)\mathbf{R}\mathbf{u}(t) \right] dt$$

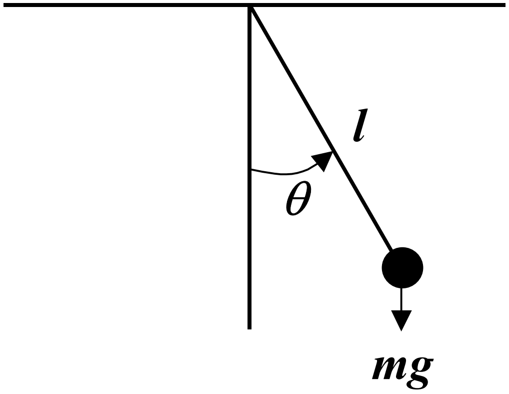
Q and R are positive-definite weighting matrices
y(t) is the output response of the system to be reduced
u(t) is the control input

The second term accounts for the control effort

Nonlinear control

When the system is nonlinear, performance of linear control system will be reduced

Need to design nonlinear controller



$$ml\ddot{\theta} + mg\sin(\theta) + kl\dot{\theta} = 0$$

$$k - friction\ \ coefficient$$

$$x_1 = \theta, \quad x_2 = \dot{\theta}$$

$$x_2 = \dot{x}_1$$

$$\dot{x}_2 = -\frac{g}{l}\sin(x_1) - \frac{k}{m}x_2$$

For equilibrium *x_2*=0, implies

$$\sin(x_1) = 0$$

$$x_1 = n\pi,\ \ n = 0, \pm 1, ...$$