Dr. Norbert Cheung's
Lecture Series

Level 5 Topic no: 10

Robust Control Issues

Contents

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Reference: Katsuhiko Ogata, "Discrete Time Control Systems", Prentice Hall

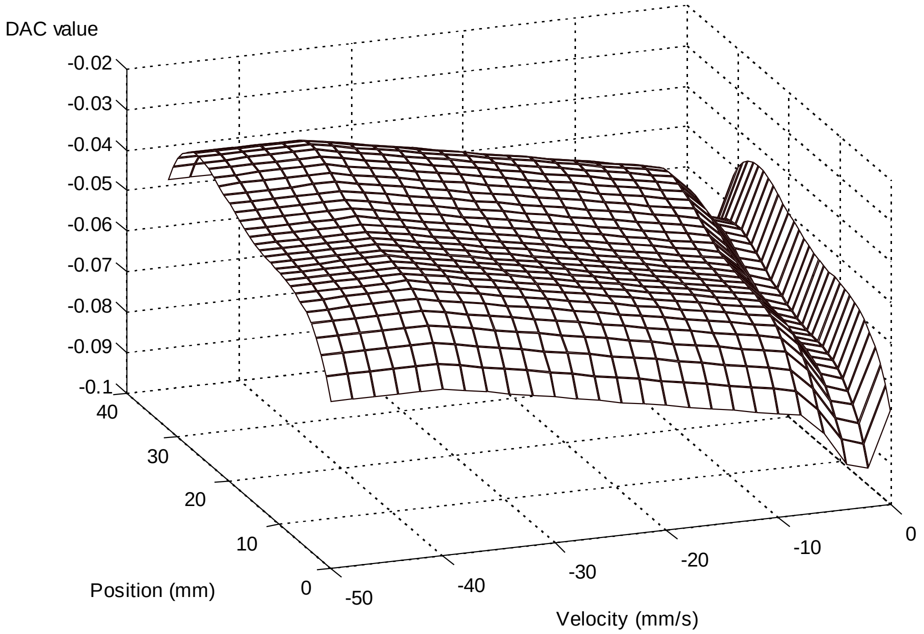
1. Introduction

Robust System: A system that maintains its original intended purpose despite system parameter variations.

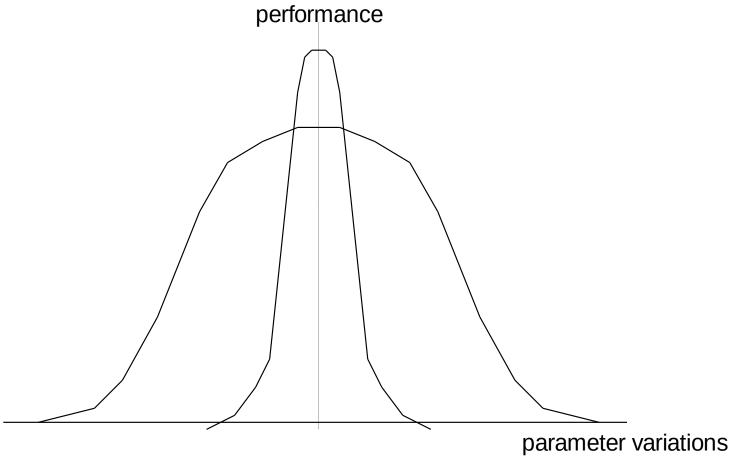
Examples of parameter variations:

1. Change of mechanical geometry (e.g. in robot manipulators)
2. Change of electrical parameters (e.g. motor gets hot)
3. Mechanical uncertainties (e.g. friction, misalignment)
4. Change of load (e.g. in pick and place machines)
5. Other factors (e.g. sensor resolution, noise, vibration)

An example of friction model (a linear slide):

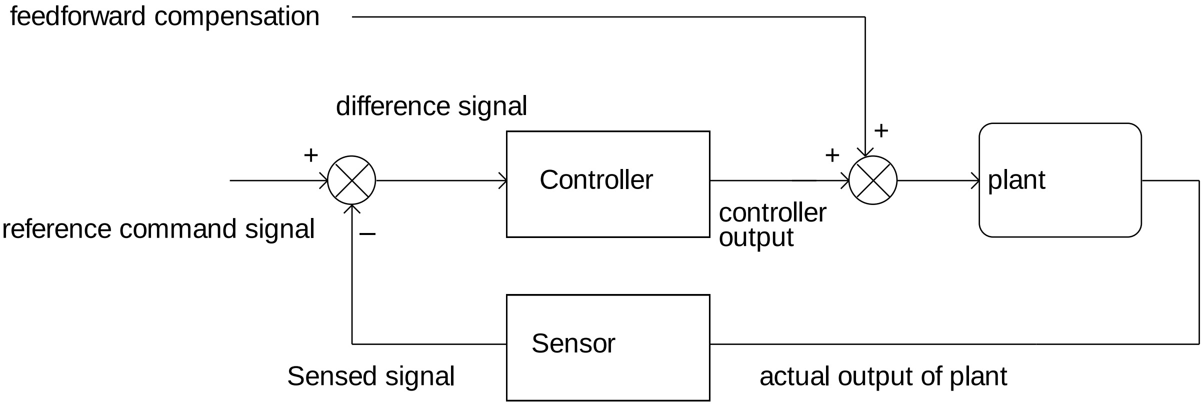


Variation of performance versus parameter variations:



2. Feed Forward Compensation

- A way to predict performance change – Predictive Systems
- Compensate the change without waiting for feedback sensor signals.
- Useful for repetitive motions
- Useful for know load change



How to generate the feed forward compensation signal? Examples:

High speed motion: acceleration compensation	
Spring loaded system: position compensation	
Fluid stirring: Velocity compensation	
Multi-axis system: Motion decoupling	

3. Estimate System Parameters

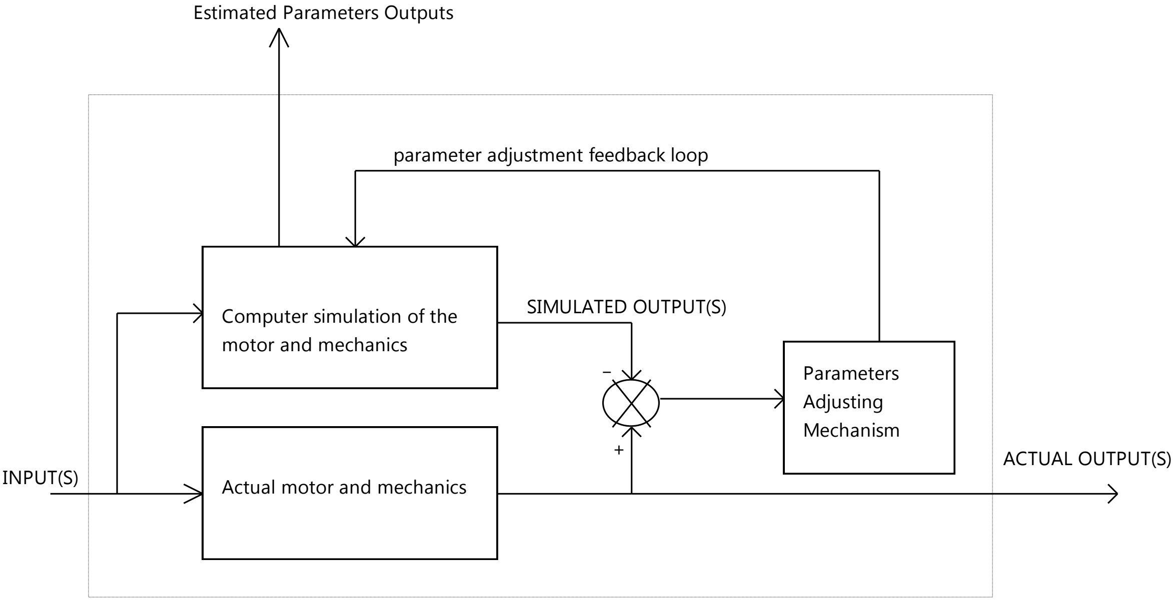
Full order observers: to run a real time simulation of the plant in parallel with the hardware, and obtain the system parameters which cannot be measured. Use these parameters to control the hardware.

Examples of observers are:

- Torque observers
- Velocity observers
- Position observers (sensorless position control)
- Flux observers

Notes:

1. We must monitor the input of the plant, as well as the output of the plant.
2. If the simulated output does not correspond with the actual output, a feedback mechanism must be used to adjust the simulated parameters.
3. The sampling rate of the feedback mechanism is related to the rate of change of the parameter variations.
4. There must be a one-to-one correspondence between input/output relationships and the system parameter changes.
5. The feedback loop must be globally stable.



Reduced State observer is also available: it does a partial simulation of the plant and obtain the useful parameters inside this partial simulation.

Example: Full order state observer for DC motor motion system.

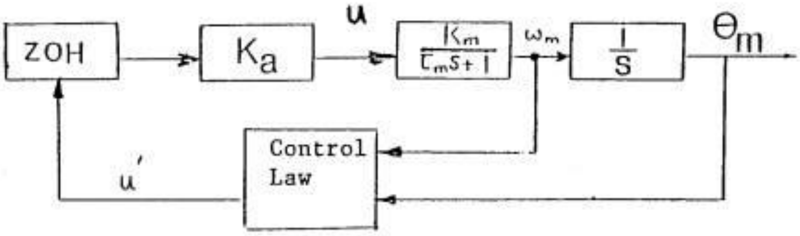


Figure 1: State Feedback Controlled System

In terms of State Space representation:

$$\begin{bmatrix} \theta(n+1) \\ \omega(n+1) \end{bmatrix} = A \cdot \begin{bmatrix} \theta(n) \\ \omega(n) \end{bmatrix} + B\ u(n) \qquad (37)$$

$$A = \begin{bmatrix} 1 & {}^1/_a(a - e^{-aT}) \\ 0 & e^{-aT} \end{bmatrix}, \quad B = \begin{bmatrix} K_m(T - {}^1/_a + {}^1/_a\, e^{-aT}) \\ K_m(1 - e^{-aT}) \end{bmatrix} \qquad (38)$$

$$u'(n) = -F \begin{bmatrix} \theta(n) \\ \omega(n) \end{bmatrix}$$

Using state variable vector , x(n), equation 37 may be represented as:

$\underline{x}(n+1) = A\,\underline{x}(n) + B\,u(n),\ \theta(n) = D\,\underline{x}(n)$

This equation is illustrated in figure 2.

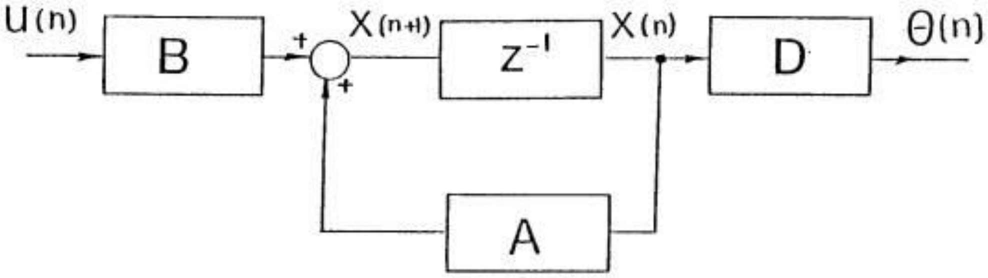


Figure 2: State Space Representation

Since the system states are not all available, we will use the controlled signal, u(n), and measured output signal $\Theta(n)$, to estimate the missing state (i.e. velocity)

$$\text{Remember: } \underline{x}(n) = \begin{bmatrix} \Theta(n) \\ \omega(n) \end{bmatrix}$$

Design of Full Order Observers for DC Motor Control

A full order observer estimates all states of a plant from the measurement of input(s) and some measurable outputs of that plant. For instance, in the following example, our observer model will use the input signal to a motor as well as the measured position to estimate the velocity and position .

The lower half of figure 3 is the state space presentation of an actual motor, whereas the top part shows an observer model implemented in software. Notice that x_e is the estimated state and Matrix G weights the error, in order to provide a corrective action on the estimation mechanism.

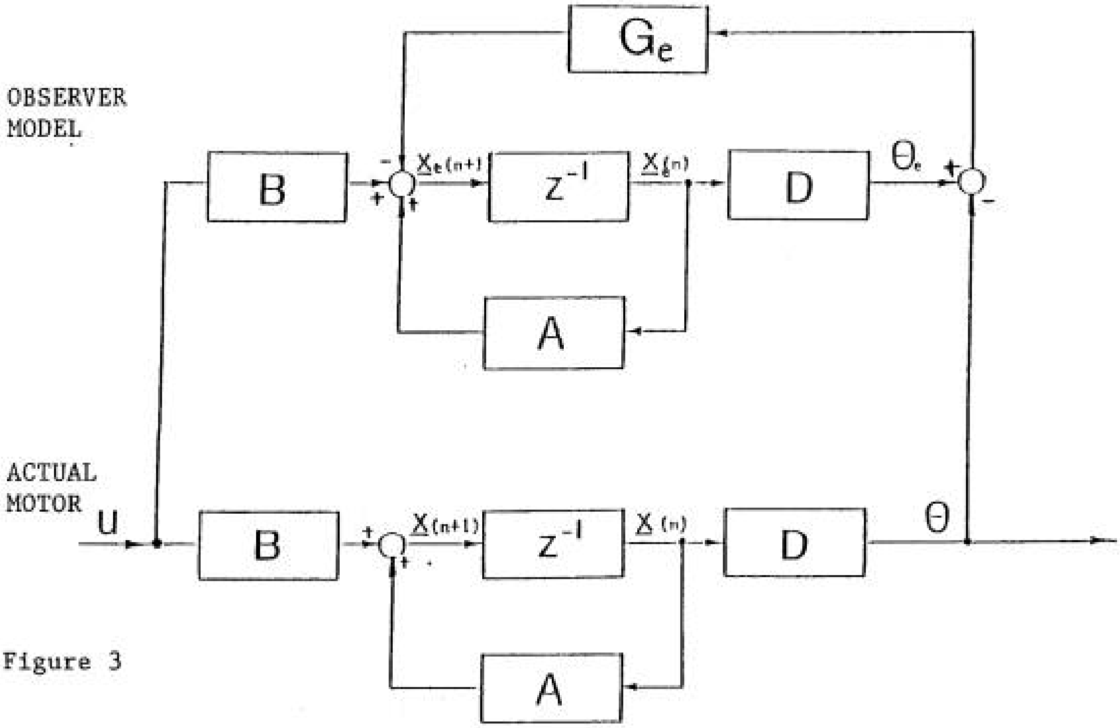
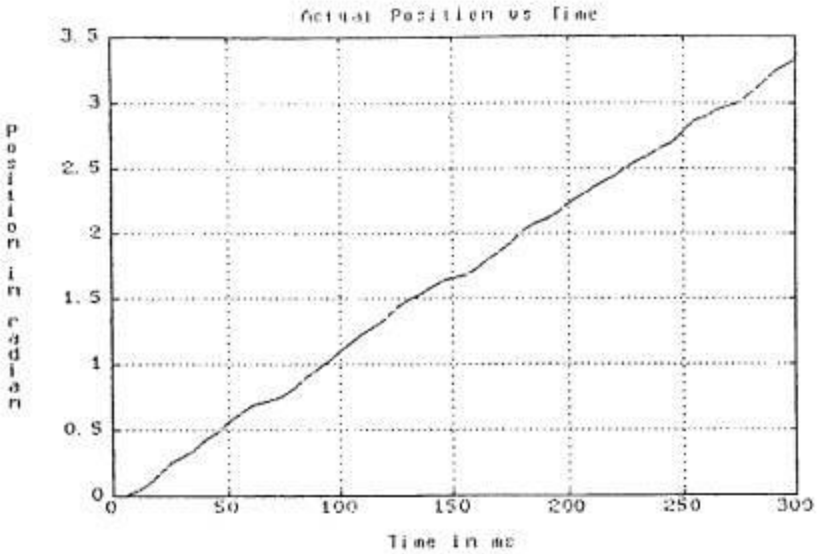
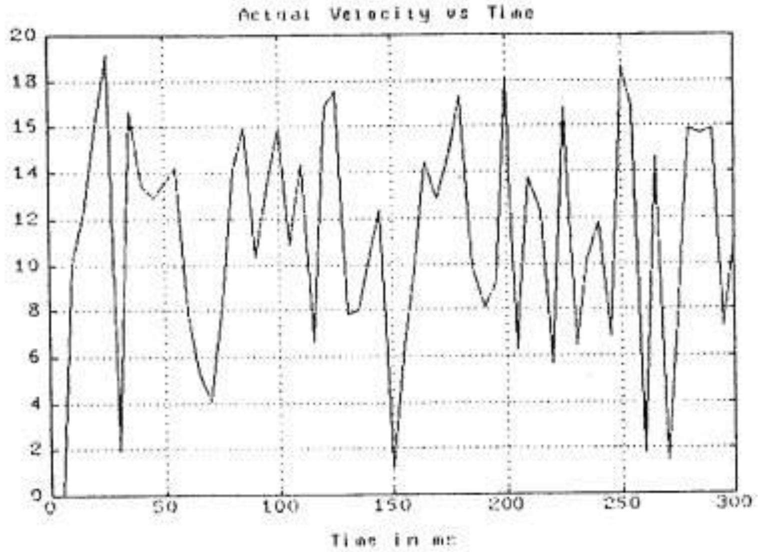
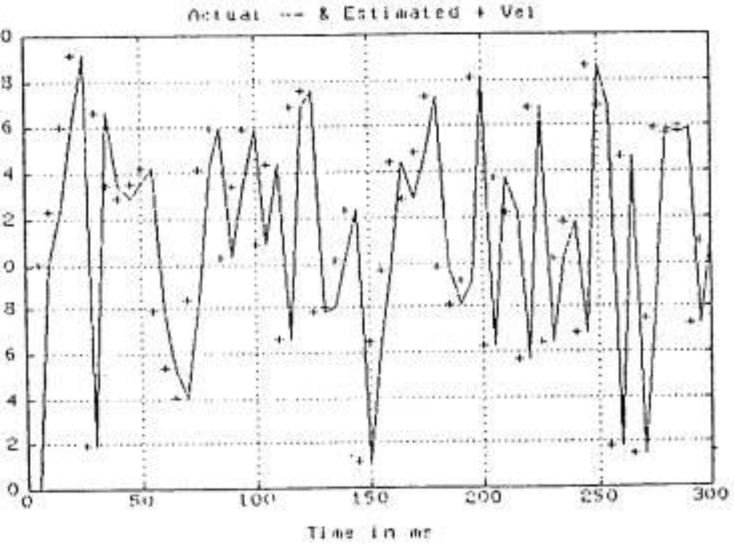


Figure 3

From this block diagram, the observer model may be derived as follows:


Actual Position vs Time
Position in radian
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
Time in ms


Actual Velocity vs Time
20
18
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Time in ms


Actual -- & Estimated + Vel
20
18
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Time in ms

2. Adaptive Control

Adaptive Control characteristics

Adaptive control involves the control of a plant that involves changing characteristics. Two commonly used configurations are: Self Tuning Regulator and Model Reference Adaptive Control

CONTROLLER DESIGN

The purpose of an identification algorithm such as we have just described is to provide a controller design-block with appropriate values of system parameters. The controller will use these to calculate a new set of control parameters. The actual design of the controller will depend upon what sort of performance is desired for a particular application.

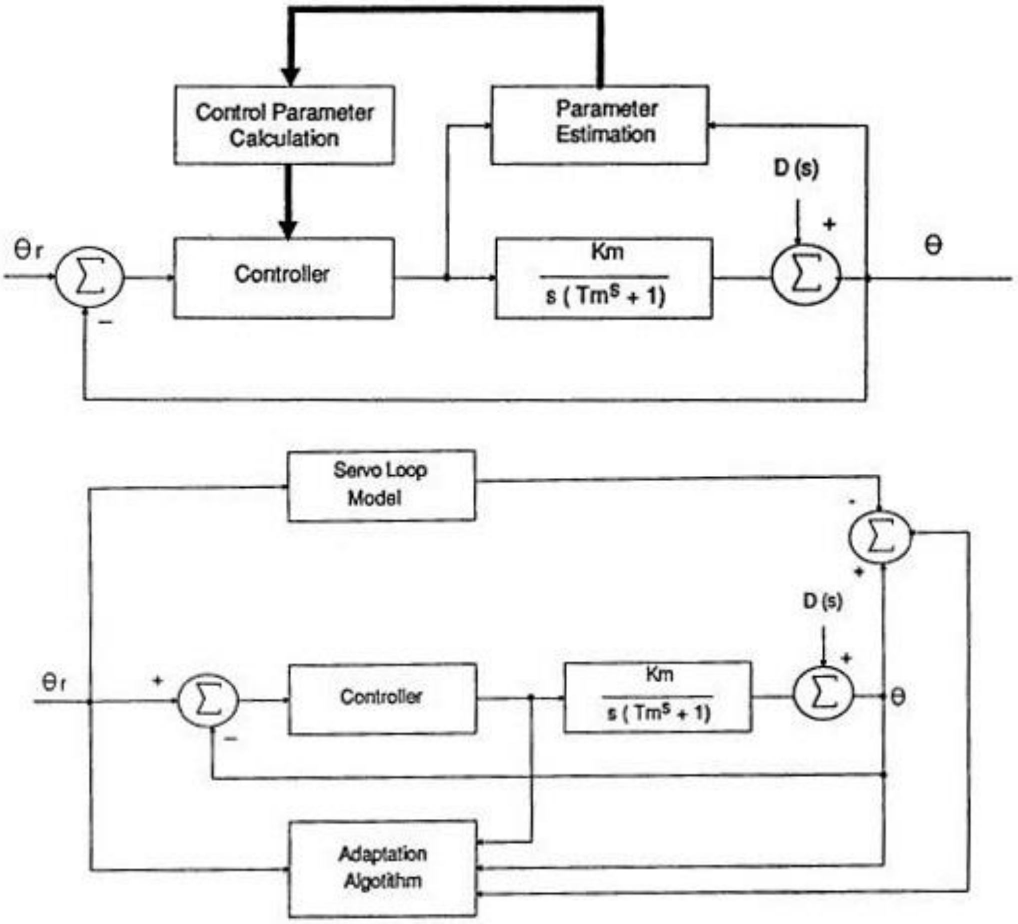
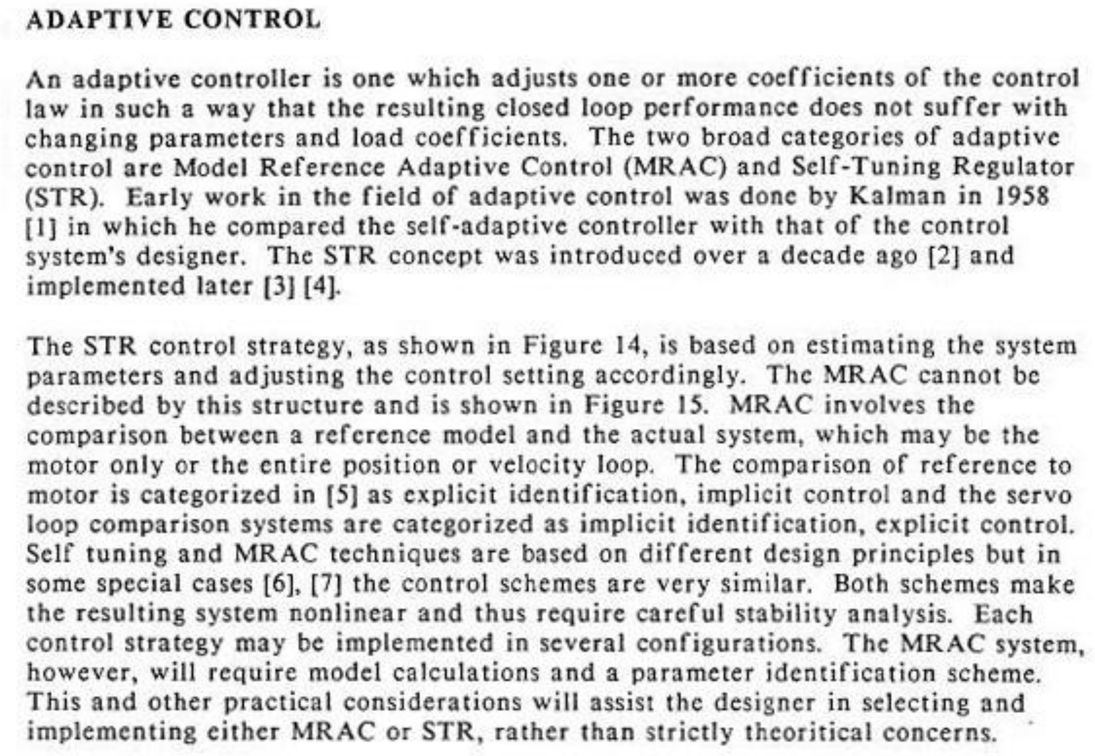


Figure 15: Model Reference Adaptive Control

Adaptive Control versus Robust Control

The adaptive controller adapt to changes of the plant.

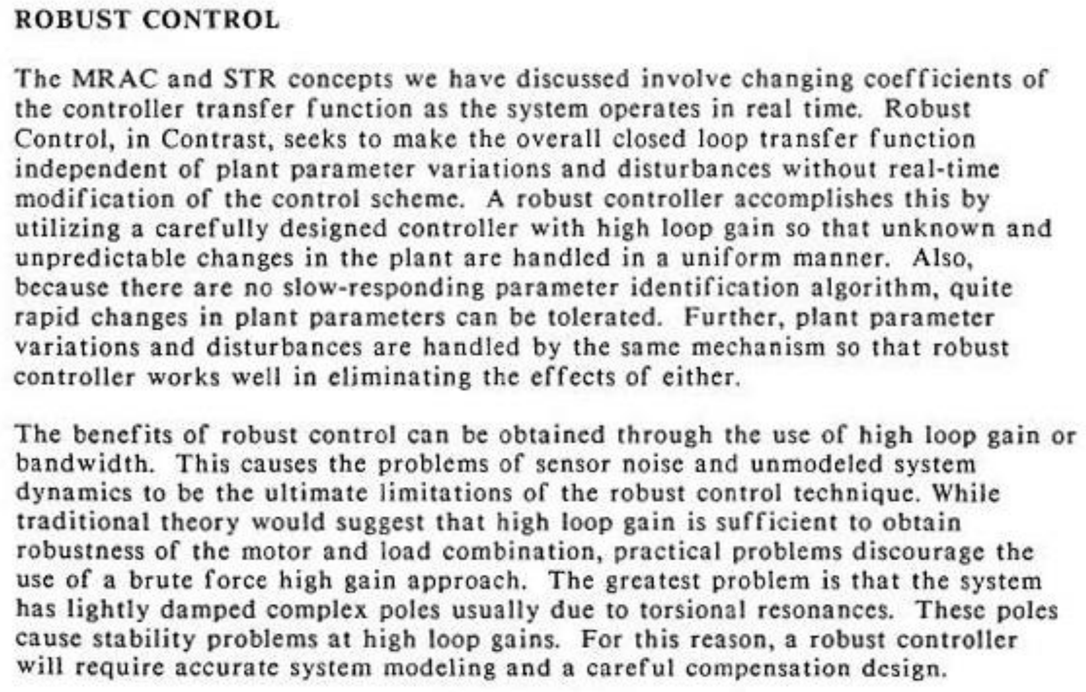
Robust control is robust enough to allow variations of system parameters in the plant.



ADAPTIVE CONTROL

An adaptive controller is one which adjusts one or more coefficients of the control law in such a way that the resulting closed loop performance does not suffer with changing parameters and load coefficients. The two broad categories of adaptive control are Model Reference Adaptive Control (MRAC) and Self-Tuning Regulator (STR). Early work in the field of adaptive control was done by Kalman in 1958 [1] in which he compared the self-adaptive controller with that of the control system's designer. The STR concept was introduced over a decade ago [2] and implemented later [3] [4].

The STR control strategy, as shown in Figure 14, is based on estimating the system parameters and adjusting the control setting accordingly. The MRAC cannot be described by this structure and is shown in Figure 15. MRAC involves the comparison between a reference model and the actual system, which may be the motor only or the entire position or velocity loop. The comparison of reference to motor is categorized in [5] as explicit identification, implicit control and the servo loop comparison systems are categorized as implicit identification, explicit control. Self tuning and MRAC techniques are based on different design principles but in some special cases [6], [7] the control schemes are very similar. Both schemes make the resulting system nonlinear and thus require careful stability analysis. Each control strategy may be implemented in several configurations. The MRAC system, however, will require model calculations and a parameter identification scheme. This and other practical considerations will assist the designer in selecting and implementing either MRAC or STR, rather than strictly theoritical concerns.



ROBUST CONTROL

The MRAC and STR concepts we have discussed involve changing coefficients of the controller transfer function as the system operates in real time. Robust Control, in Contrast, seeks to make the overall closed loop transfer function independent of plant parameter variations and disturbances without real-time modification of the control scheme. A robust controller accomplishes this by utilizing a carefully designed controller with high loop gain so that unknown and unpredictable changes in the plant are handled in a uniform manner. Also, because there are no slow-responding parameter identification algorithm, quite rapid changes in plant parameters can be tolerated. Further, plant parameter variations and disturbances are handled by the same mechanism so that robust controller works well in eliminating the effects of either.

The benefits of robust control can be obtained through the use of high loop gain or bandwidth. This causes the problems of sensor noise and unmodeled system dynamics to be the ultimate limitations of the robust control technique. While traditional theory would suggest that high loop gain is sufficient to obtain robustness of the motor and load combination, practical problems discourage the use of a brute force high gain approach. The greatest problem is that the system has lightly damped complex poles usually due to torsional resonances. These poles cause stability problems at high loop gains. For this reason, a robust controller will require accurate system modeling and a careful compensation design.

5. Steps in Control System Design

Controller design usually involves the following steps

Steps	Process
Identification	
Modeling	
Control Strategy Development	
Simulation	
Implementation	
Performance Evalution	

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