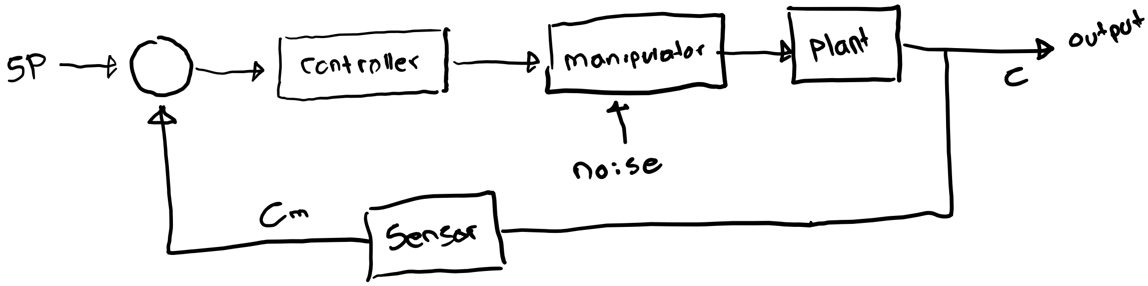
Chapter 6

6.1 Introduction

Classical control systems:

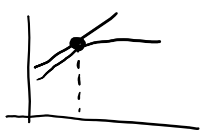


SP – setpoint
C_m – measured error

$\text{error} = SP - C_m \leq \text{threshold}$

Classical control
PI control, PD control, P control, gravitated complex control, PID control

P – proportional
I – integral
D – derivative



H_∞, adaptive, sliding mode
linear systems

If the system (plant) is very non-linear, parameters are time variant (e.g. process control)
environment – noisy

Plant model → linear PDEs
complex non-linear systems
I.C. ~ approximate reasoning

6.2 Fuzzy and NF Control

Fuzzy reasoning → fuzzy logic
fuzzy system parameters → trained

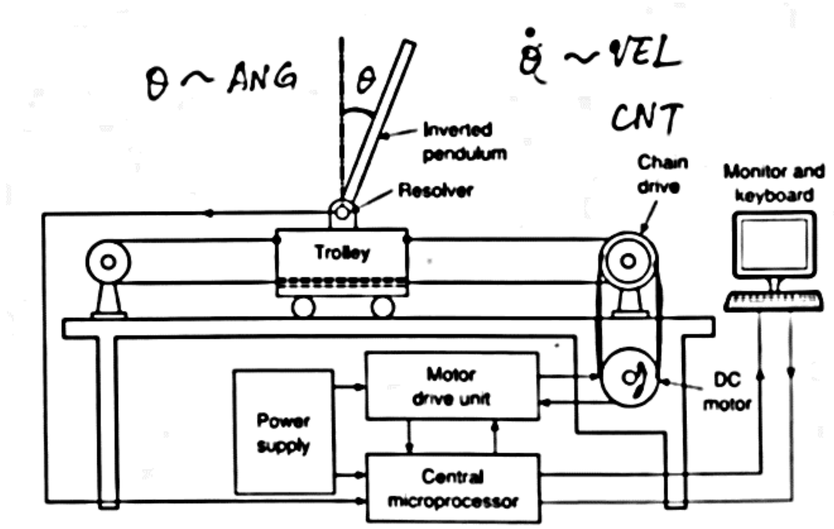
Question 3.3 (Book 1)

Consider the experimental setup of an inverted pendulum shown in Figure P3.3. Suppose that direct fuzzy logic control is used to keep the inverted pendulum upright. The process measurements are the angular position, about the vertical (ANG) and the angular velocity (VEL). The control action (CNT) is the current of the motor driving the positioning trolley. The variable ANG takes two fuzzy states: positive large (PL) and negative large (NL). Their memberships are defined in the support set $[-30°,\ 30°]$ and are trapezoidal. Specifically,

$$\mu_{PL} = \begin{cases} 0 & \text{for } ANG = \{-30°,\ -10°\} \\ \text{linear}(0, 1.0) & \text{for } ANG = \{-10°,\ 20°\} \\ 1 & \text{for } ANG = \{20°,\ 30°\} \end{cases}$$

NF

$$\mu_{NL} = \begin{cases} 0 & \text{for } ANG = \{-30°,\ -20°\} \\ \text{linear}(1.0, 0) & \text{for } ANG = \{-20°,\ 10°\} \\ 1 & \text{for } ANG = \{10°,\ 30°\} \end{cases}$$



The variable VEL takes two fuzzy states PL and NL which are quite similarly defined in the support set $[-60°/s\ \ 60°/s]$. The control inference CNT can take two states: positive large (PL), no change (NC), and negative large (NL). Their membership functions are defined in the support set $[-3A,\ 3A]$ and are either trapezoidal or triangular. Specifically,

$$\mu_{PL} = \begin{cases} 0 & \text{for } CNT = \{-3A,\ 0\} \\ \text{linear}(0, 1.0) & \text{for } CNT = \{0,\ 2A\} \\ 1 & \text{for } CNT = \{2A,\ 3A\} \end{cases}$$

$$\mu_{NC} = \begin{cases} 0 & \text{for } CNT = \{-3A,\ -2A\} \\ \text{linear}(0, 1.0) & \text{for } CNT = \{-2A,\ 0\} \\ \text{linear}(1.0, 0) & \text{for } CNT = \{0,\ 2A\} \\ 0 & \text{for } CNT = \{2A,\ 3A\} \end{cases}$$

$$\mu_{PL} = \begin{cases} 1.0 & \text{for } CNT = \{-3A,\ -2A\} \\ \text{linear}(1.0, 0) & \text{for } CNT = \{-2A,\ 0\} \\ 0 & \text{for } CNT = \{0,\ 3A\} \end{cases}$$

The following four fuzzy rules are used in control:

If ANG is PL and VEL is PL then CNT is NL

elseif If ANG is PL and VEL is NL then CNT is NC

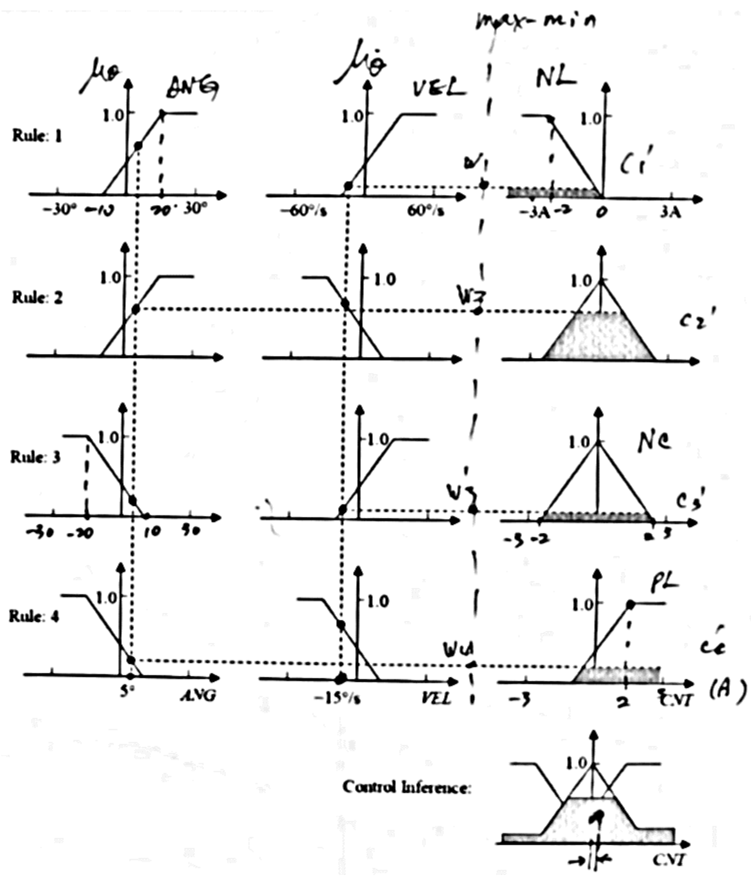
elseif If ANG is NL and VEL is PL then CNT is NC

elseif If ANG is NL and VEL is NL then CNT is PL

end if

a) Sketch the four rules in a membership function diagram for the purpose of making control inferences using individual rule-based inference.

b) If the process measurements of $ANG = 5°$ and $VEL = 15\ °/s$ are made, indicate on your sketch the corresponding control inference.

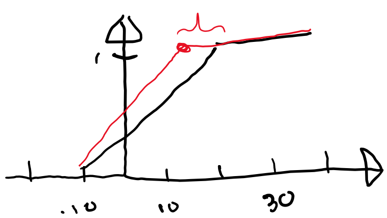


(2) NF control:

Optimize MF parameters and consequent parameters.

If MF parameters are non-linear,

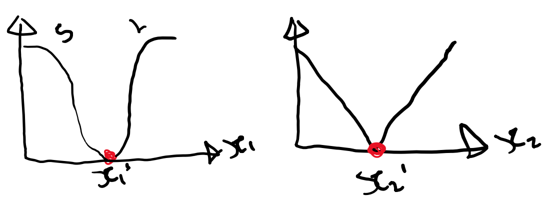
- If the consequent parameters are linear
  Then → $GD + LSE$
- If the consequent parameters are non-linear
  Then → $GD + GD\ (or\ NG, LM, etc.)$
  Even if GD is used twice, it is still a hybrid method, since they are used independently (and for different system aspects)



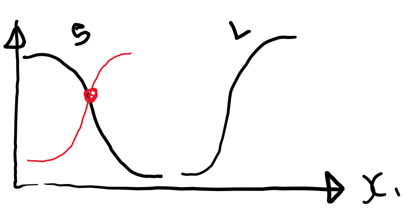
(3) Properties of Fuzzy Control (or NF Control)

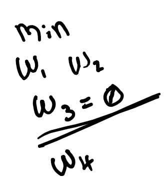
1) Completeness
Rule base should be "complete"

Given an input, there is at least one active rule.



2) Continuity
There is no gap between MFs





3) Consistency
No contradictory rules

$\mathcal{R}_3$: if x is L then y is M
…
$\mathcal{R}_9$: if x is L then y is L

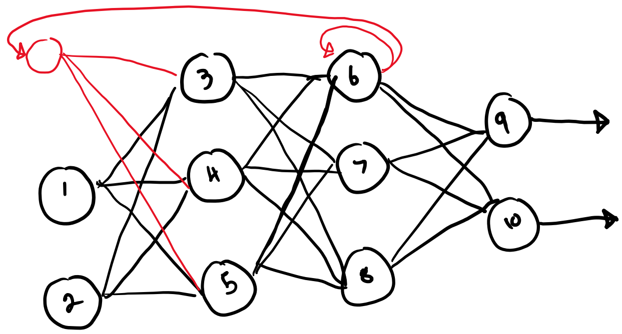
4) No interaction
Interaction: rules are coupled

if A_1 and B_1 then C_1 and D_1
else if A_2 and B_2 then C_2 and D_2
else if …

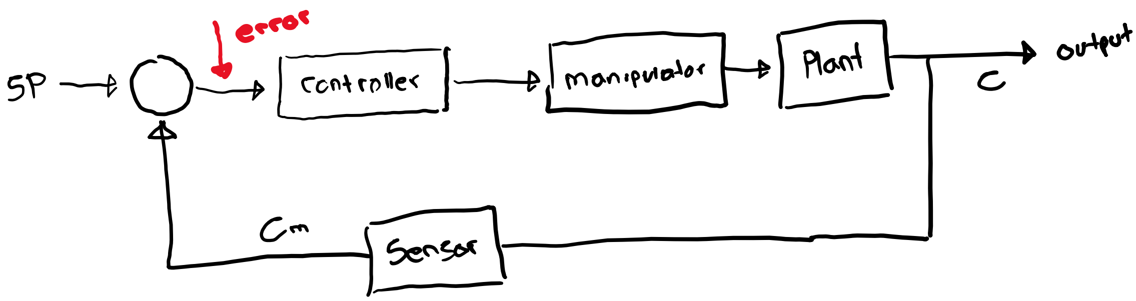
5) Other rules
Validity, …, etc.

6.3 NN-based System Identification and Control

ANNs, Recurrent NNs, feed-forward NNs

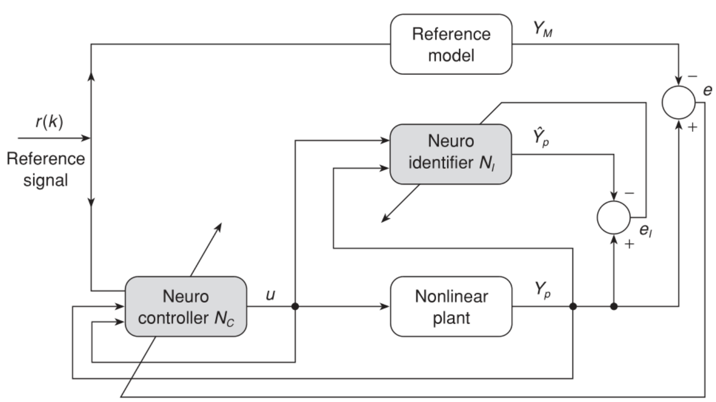


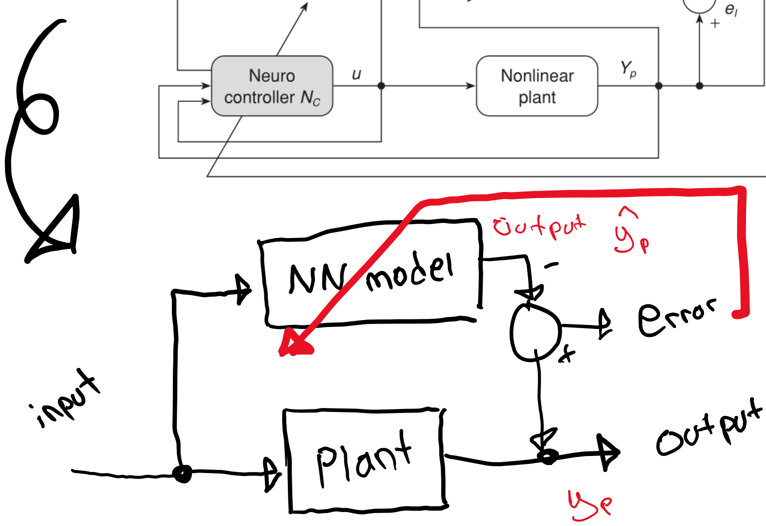
- NN-based controller



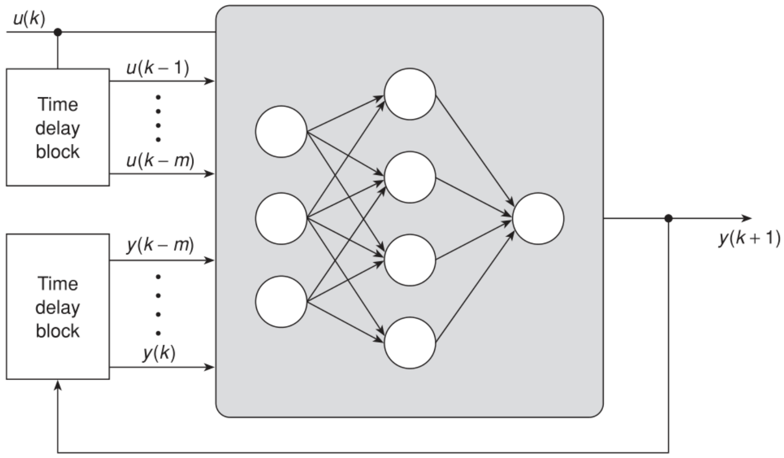
- NNs to model plant

System identification to identify system model.

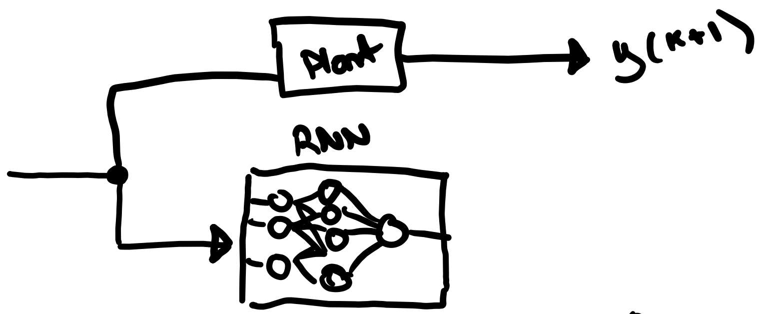




Time delayed recurrent neural network:



- Series-parallel



$$\{u(k), u(k-1), u(k-2), \dots, u(k-m)\}$$

Previous output:

$$\{y(k), y(k-1), y(k-2), \dots, y(k-m)\}$$

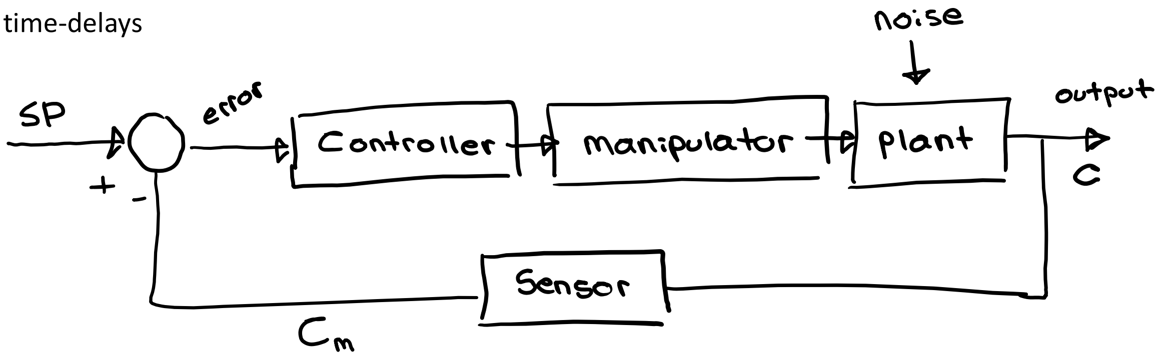
Plant's real output: $y(k+1)$
RRN output: $\hat{y}(k+1)$
Error:

$$e(k+1) = y(k+1) - \hat{y}(k+1)$$

- There is also parallel method (next page)

6.3 NN-based System Identification and Control

Highly non-linear
time-varying
dynamic coupling
time-delays

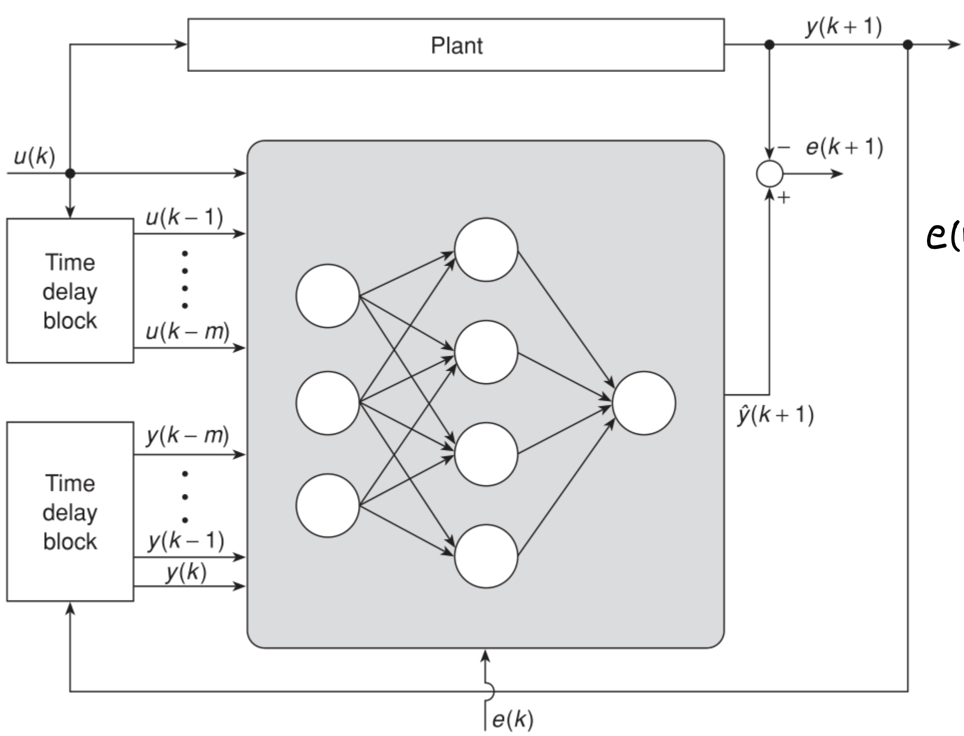


$\text{error} = \text{SP} - \text{C}_\text{m}$

model → plant dynamics
PDE modeling

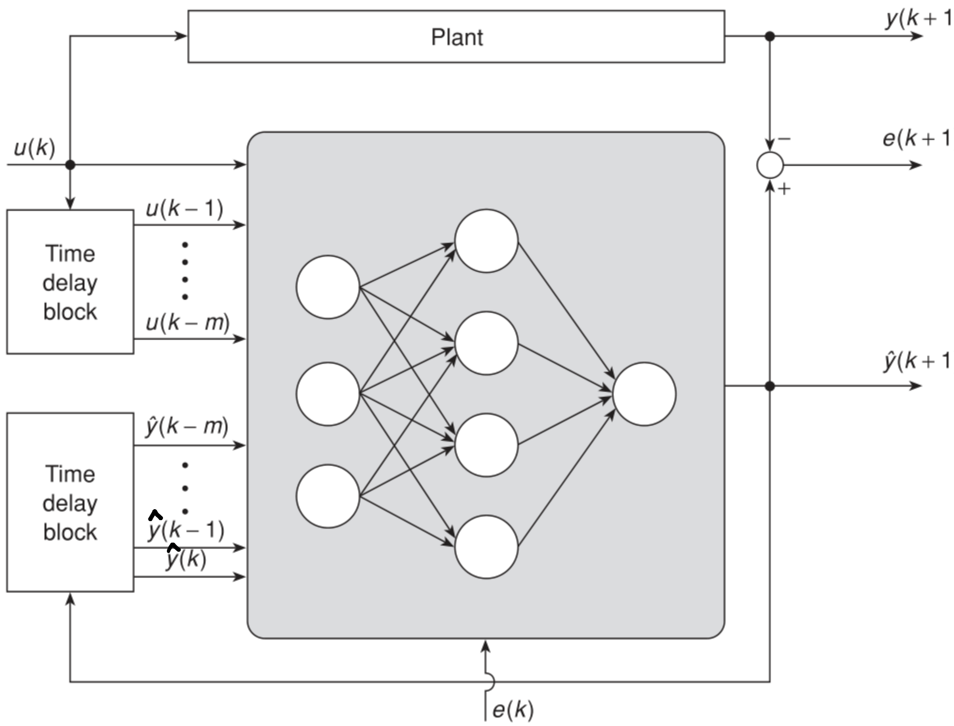
FFNN-based } models
RNN-based

- Series-parallel method:



error
$e(k+1) = y(k+1) - \hat{y}(k+1)$

- Parallel method:



- NN-controllers

PID ~ P gain, I gain, D gain