The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Mechanical Egineering

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Study Programme	:	Bachelor of Technology Honours in Engineering
Name of the Examination	:	Final Examination
Course Code and Title	**:**	**DMX7306 Intelligent Control Systems**
Academic Year	:	2021/2022
Date	:	28th February 2023
Time	:	13.30-16.30
Duration	:	**3 hours**

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Six (6)** questions in **Seven (7)** pages.
3. Answer **Question 1**, which is **compulsory**, and **three** others.
4. Question 01 carries 40 marks and others 20 marks each.
5. Answer for each question should commence from a new page.
6. This is a Closed Book Test (CBT).
7. Answers should be in clear handwriting.
8. Do not use Red colour pen.

Question 01

Active Suspension System

A vehicle's suspension system typically consists of springs and shock absorbers that help to isolate the vehicle chassis and occupants from sudden vertical displacements of the wheel assemblies during driving. A well-tuned suspension system is important for the comfort and safety of the vehicle occupants as well as the long-term durability of the vehicle's electronic and mechanical components.

The suspension systems in most vehicles on the road today are passive. The chassis of the vehicle is attached to the axles or wheel assemblies through coil springs or leaf springs that help to protect the chassis from sudden vertical forces applied to the wheels. The shock absorbers help to dissipate the energy applied to the springs and damp the oscillations that would normally occur when a brief excitation is applied to a mass-spring system.

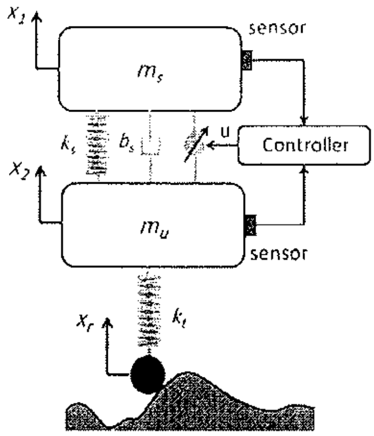


Figure Q1

Active suspension systems sense the forces being applied to the wheels and constantly adjust the mechanical connections between the chassis and wheel assemblies to keep the chassis level and/or optimally absorb the energy associated with the vertical motion of the wheels. Additionally, with the advent of increased computer control, various options of suspension travel and response can be adjusted by the driver while driving.

As shown in Figure Q1, m_s denotes the mass on the spring and m_u denotes the mass under the spring; x_r denotes the road disturbance excitation, x_2 denotes the vertical displacement of the mass under the spring, and x_1 denotes the vertical displacement of the mass on the spring; b_s denotes the suspension equivalent damping; k_t is the tire equivalent stiffness and k_s is the suspension stiffness; and u is the actuator active control force.

a) Select suitable the sensors and actuators considered in the active suspension system shown in figure Q1. Explain the operation of each sensor and actuator. [5]

b) Derive the state equation of the active suspension model shown in figure Q1. [10]

c) Develop the control system block diagram to control active suspension system by using PD-Like Fuzzy controller. You should clearly indicate inputs, outputs, feedbacks and necessary components. [5]

d) Design suitable PD-Like Fuzzy controller, you should clearly explain following steps.

   i. Fuzzification

   ii. Rules & Rule Base

   iii. Defuzzification

Note: You can select appropriate numerical ranges for each variable and state any assumptions. [20]

Question 02

a) Briefly explain "Knowledge-Based Intelligent Control" in the context of control systems engineering by using suitable example. [5]

b) Briefly explain the Three-levels in an intelligent control architecture. [5]

c) Briefly explain the advantages and disadvantages of hybrid intelligent controllers [5]

d) What are the challenges involved in designing and implementing intelligent control systems in complex environments? [5]

Question 03

A Fuzzy PID controller is a hybrid intelligent control system that combines the benefits of both PID and fuzzy logic control methods.

a) Briefly explain following Fuzzy PID combinations with necessary block diagrams.

1) PD-Like Fuzzy Controller.
2) PI-Like Fuzzy Controller.
3) PID-Like Fuzzy Controller. [6]

b) Consider a magnetic levitation system model is:

$$y(k) = 0.6 \times y(k-1) + u(k-1)$$

PI-Like FLC is designed to regulate this system around a set point of **R=2**. Five fuzzy sets are used to represent the linguistic variables **NB, NS, Z, PS** and **PB** for the controller both input and output variables. Triangular membership functions are used to represent these fuzzy sets and define on the normalized domain [-1,1] as shown in figure Q3(a). The suggested rule-base is depicted in the figure Q3(b). If the measured parameters are obtained as **y(k-1) = 1.5** and **u(k-1) = 0.5**, find the controller output signal taking into account the actual domain of the controller variables is [2,2].

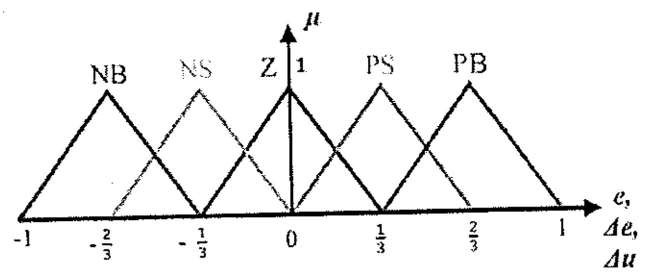


Figure Q3(a)

Knowledge Base		e(k)				
		NB	NS	Z	PS	PB
$\Delta e(k)$	NB	NB	NB	NB	NS	Z
	NS	NB	NB	NS	Z	PS
	Z	NB	NS	Z	PS	PB
	PS	NS	Z	PS	PB	PB
	PB	Z	PS	PB	PB	PB

Figure Q3(b)

[14]

Question 04

a) Describe the key difference between a Mamdani controller and a Takagi-Sugeno Controller. [3]

b) A fuzzy set A and B in the universe R whose membership function is given by

$\mu_A(x) = 1 - (0.5|x - 3|)$ For $1 \le x \le 5$ = 0 otherwise
$\mu_B(x) = 1 - (0.5|x - 4|)$ For $2 \le x \le 6$ = 0 otherwise

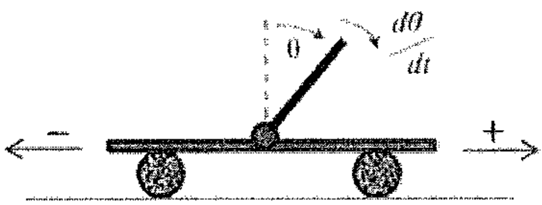
1) Sketch and describe the membership functions $\mu_A(x)$ and $\mu_B(x)$.

2) Determine A∪B

3) Determine A∩B

4) What is α-cut of B for α=0.5 [5]

c) Figure Q4 shows two input, single output Pole-Balancing control system: The input variables, $\boldsymbol{\theta}$ and $\boldsymbol{d\theta}$ and η is the output variable for actuator.



The variables belong to the universes of discourse **X1, X2** and **Y** respectively, such that **θ∈X1 = [-2,2], dθ∈X2 = [-5,5] and η∈Y = [-16,16]**. The fuzzy partitions of the sets X1, X2 and Y are given as

For X1

$$NEG_{\mu(\theta)} = \begin{cases} 1 & -2 \geq \theta \\ -0.5\theta & -2 < \theta < 0 \end{cases}$$

$$ZERO_{\mu(\theta)} = \begin{cases} 0.5\theta + 1 & -2 < \theta < 0 \\ -0.5\theta + 1 & 0 < \theta < 2 \end{cases}$$

$$POS_{\mu(\theta)} = \begin{cases} 0.5\theta & 0 < \theta < 2 \\ 1 & 2 \leq \theta \end{cases}$$

For X2

$$NEG_{\mu(d\theta)} = \begin{cases} 1 & -5 \geq d\theta \\ -0.2d\theta & -5 < d\theta < 0 \end{cases}$$

$$ZERO_{\mu(d\theta)} = \begin{cases} 0.2d\theta + 1 & -5 < d\theta < 0 \\ -0.2d\theta + 1 & 0 < d\theta < 5 \end{cases}$$

$$POS_{\mu(d\theta)} = \begin{cases} 0.2d\theta & 0 < d\theta < 5 \\ 1 & 5 \leq d\theta \end{cases}$$

For Y

$$BN_{\mu(y)} = \begin{cases} 1 & -16 \geq y \\ -0.125y - 1 & -16 < y < -8 \end{cases}$$

$$N_{\mu(y)} = \begin{cases} 0.125y + 2 & -16 < y < -8 \\ -0.125y & -8 < y < 0 \end{cases}$$

$$Z_{\mu(y)} = \begin{cases} 0.125y + 1 & -8 < y < 0 \\ -0.125y + 1 & 0 < y < 8 \end{cases}$$

$$P_{\mu(y)} = \begin{cases} 0.125y & 0 < y < 8 \\ -0.125y + 2 & 8 < y < 16 \end{cases}$$

$$BP_{\mu(y)} = \begin{cases} 0.125y - 1 & 8 < y < 16 \\ 1 & 16 \leq y \end{cases}$$

1) Sketch the corresponding Fuzzy Sets for input and output variables. [2]

2) Develop appropriate rule base and state corresponding rules (use AND function for rule evaluation). [3]

3) Compute the control values η for the input values of $(\theta, d\theta)$ = **(-1.5, 2).** Show all the four stages of the computation: fuzzification, inference, composition and defuzzification. [7]

Question 05

a) Briefly explain Neuro-Fuzzy System (NFS) architecture based on Mamdani approach with necessary diagram. [3]

b) Consider a Neuro-Fuzzy system with three input variables **X, Y, and Z** and one output variable **O**. The membership functions for **X, Y,** and **Z** are triangular with the following parameters:

X: a = 1, b = 5, c = 9

Y: a = 2, b = 6, c = 10

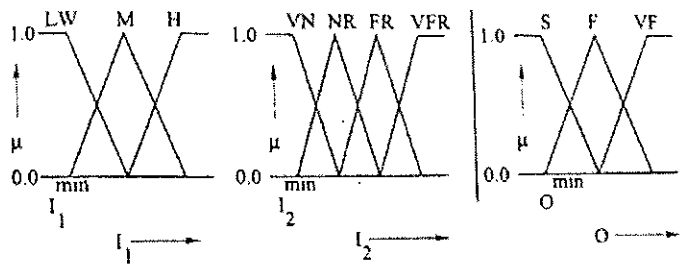
Z: a = 3, b = 7, c = 11

The rule base consists of three rules:

- If X is low and Y is medium and Z is high, then O is low
- If X is medium and Y is high and Z is medium, then O is high
- If X is high and Y is low and Z is low, then O is medium

Given the input values X=3, Y=8, Z=10, use the Neuro-Fuzzy system to determine the output value O. [5]

c) Figure Q5(a) shows fuzzy logic input and output sets developed for vehicle speed control system and figure Q5(b) shows the proposed rule-base for fuzzy logic controller, based on this information, design proper Neuro-Fuzzy architecture based on Mamdani approach. [12]



LW: Low
M: Medium
H: High
VN: Very Near
NR: Near

FR: Far
VFR: Very Far
S: Slow
F: Fast
VF: Very Fast

Figure Q5(a)

		I_2			
		VN	NR	FR	VFR
	LW	S	S	F	F
I_1	M	S	F	F	VF
	H	S	F	VF	VF

Figure Q5(b)

Question 06

a) Which control method would you recommend for each of the following applications?

1) Servo control with a permanent-magnet DC motor (linear).

2) Active control of a vehicle suspension system (linear, multivariable).

3) Control of a self-diving automated vehicle (nonlinear, complex, difficult to model). [3]

b) What are the available Evolutionary Algorithms (EA)? briefly explain three of them. [3]

c) Explain the concept of adaptive Neuro-Fuzzy inference systems (ANFIS) and their applications. [2]

d) What are the available approaches to Improv the accuracy of a neural network. [2]

e) Design and explain the application of neural network for robot arm dynamics shows in figure Q6. [10]

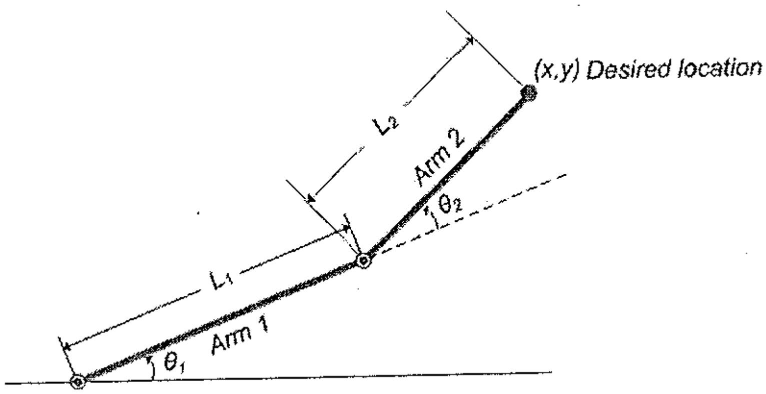


Figure Q6

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