(22) 00074

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

Study Programme	: Bachelor of Technology Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	**:DMX6573/MEX6273 Advanced control engineering**
Academic Year	: 2017/18
Date	:6th February 2019
Time	: 0930-1230hrs
Duration	**: 3 hours**

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Seven (7)** questions in **eight (8)** pages.
3. **SECTION A, Answer Q1**, which is **compulsory**, and **FOUR** other questions selecting **2 from SECTION B** and **2 from SECTION C**.
4. Answer for each question should commence from a new page.
5. Relevant charts/ codes are provided.
6. This is a Closed Book Test (CBT).
7. Answers should be in clear hand writing.
8. Do not use Red colour pen.

SECTION A

Q1. (spend approximately one hour)

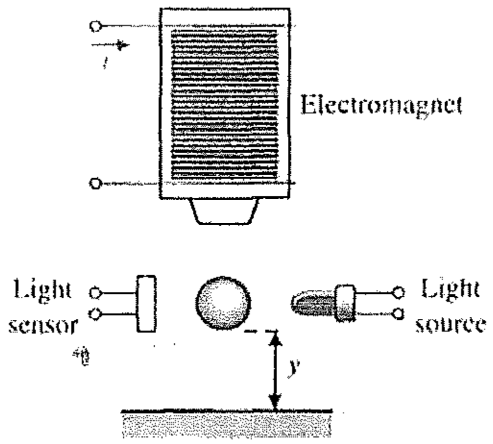

Figure Q1_a

The sketch of magnetic levitation system shown in figure Q1_a. The Magnetic Levitation system is comprised of an electromagnet coupled with a ball position sensor and a steel ball. The magnetic ball suspension system can be further sub-divided into a mechanical system paired with an electrical system. The ball, which is an element of the mechanical system, can be controlled by means of varying the current passing through the electromagnet which in turn can be controlled by the application of a controlled voltage across the electromagnets terminals. The open loop transfer function of the Magnetic Levitation system is shown in figure Q1_b and the state feedback control signal is given in equation (1).

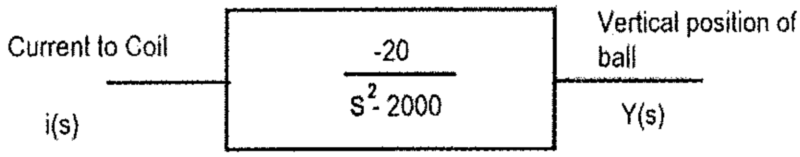

Figure Q1_b

$$i = -k_1 x_1 - k_2 x_2 + \beta r \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Obtain a design that will provide a stable response where the ball will remain within 10% of its desired position. Assume that y and $\frac{dy}{dt}$ are measurable.

(a) Draw the complete block diagram of the Magnetic Levitation ball position control system. [10 marks]

(b) Derive the state space model for open loop Magnetic Levitation ball position control system. [10 marks]

(c) Derive the state space model for closed loop Magnetic Levitation ball position control system. [10 marks]

(d) Obtain a design that will provide a stable response where the ball will remain within 10% of its desired position. [10 marks]

SECTION B

Q2.

(a) Explain what is meant by the term, feedback linearization. Discuss the advantages and disadvantages of the feedback linearization approach in nonlinear control system design. [3 marks]

(b) Consider the partially feedback linearizable two-state system

$$\begin{aligned} \dot{x}_1 &= -\alpha x_1^3 + x_2 \\ \dot{x}_2 &= -\sin(x_1) + (1 + |x_2|)u \end{aligned}$$

Where $\alpha > 0$. A nonlinear control law which feedback linearizes the second state equation is to be used in conjunction with the linear state-feedback control law

$$v = -k_1 x_1 - k_2 x_2 \qquad k_1, k_2 > 0$$

i. Derive the nonlinear control law which linearizes the second state-equation. [4 marks]

ii. Prove that the control law derived in part i) combined with the linear state-feedback above globally stabilizes the origin ($x_1 = 0$, $x_2 = 0$) of the system [4marks]

iii. In the system, the term $(1 + |x_2|)$is found to be incorrect and, instead, is replaced simply by the term (1+ x). What are the implications of this replacement on the feedback linearizing control law? Explain your answer. [4marks]

Q3.

Consider the system represented in state variable form

$$\dot{X} = Ax + Bu$$
$$y = Cx + Du$$

$$A = \begin{vmatrix} 1 & 2 \\ -6 & -12 \end{vmatrix},\ B = \begin{vmatrix} -5 \\ 1 \end{vmatrix},\ C = |4 \quad -3|,\ D = |0|$$

(a) Verify that the system is observable and controllable [5 mark]

(b) If so, design a full-state feedback law and an observer by placing the closed-loop system poles at $s_{1,2} = -1 \pm j$ and the observer poles at $s_{1,2} = -12$.

[10 marks]

Q4.

A manufacturer uses an adhesive to form a seam along the edge of the material, as shown in FigureQ4_a. It is critical that the glue be applied evenly to avoid flaws; however, the speed at which the material passes beneath the dispensing head is not constant. The glue needs to be dispensed at a rate proportional to the varying speed of the material. The controller adjusts the valve that dispenses the glue. The system can be represented by the block diagram shown in Figure Q4_b, where $G_p(s) = 2/(0.03s + 1)$ with a zero-order hold $G_0(s)$.

Use a controller D(z) that represents an integral controller

$$D(z) = \frac{KTz}{z-1}$$

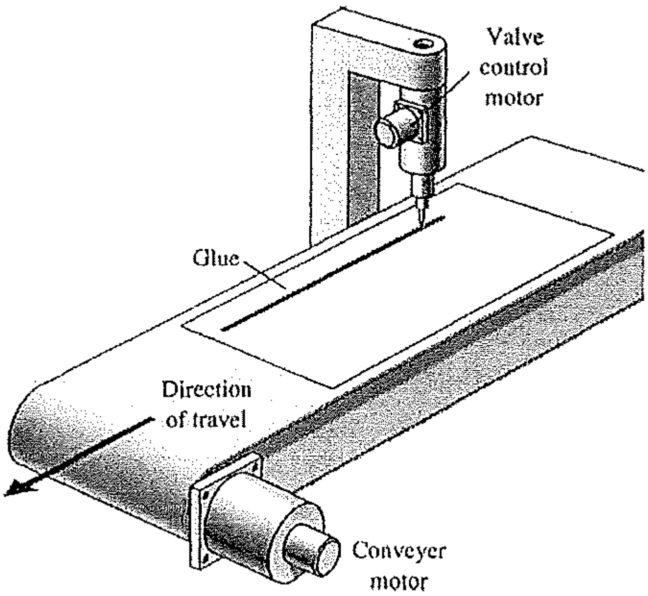

Figure Q4_a

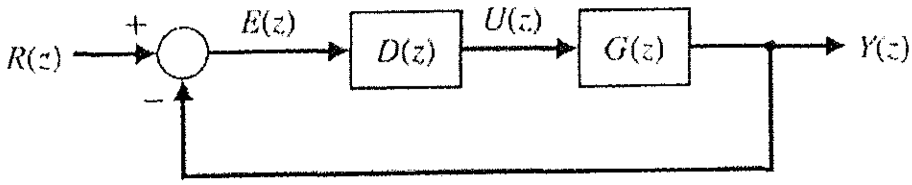

Figure Q4_b

(a) Determine G(z)D(z) for T = 30 ms, [5 marks]

(b) Plot the root locus. Select an appropriate gain K and plot the step response.

[10 marks]

SECTION C

Q5.

(a) Which control method would you recommend for each of the following applications from P Control. PI control, PID control, LQR Control, Adaptive control and Knowledge based control. and briefly explain the reasons for each system.

i) Servo control of a single axis positioning table with permanent magnet DC Motor [2 marks]

ii) Active control of a vehicle suspension system (liner, multivariable). [2 marks]

iii) Control of a rotary cement kiln (nonlinear, complex, difficult to model). [2 marks]

(b) Two fuzzy set A and B are represented by the membership function shown in figure Q5.

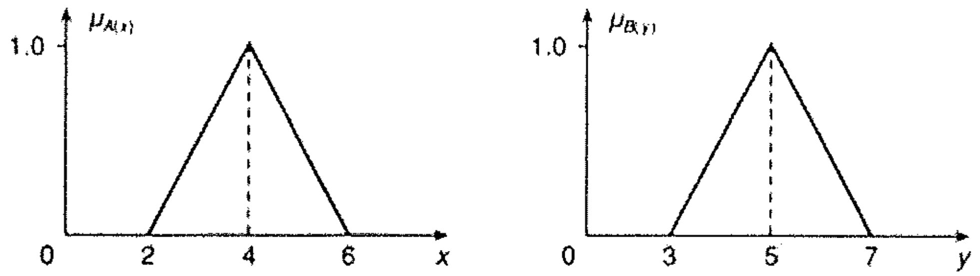

Figure Q5

i) Sketch the membership function of following relations

(1) $A \cap B$

(2) $A \cup B$

(3) not A

(4) $A \rightarrow B$ [9 marks]

Q6.

The following diagram represents a feed-forward neural network with one hidden layer:

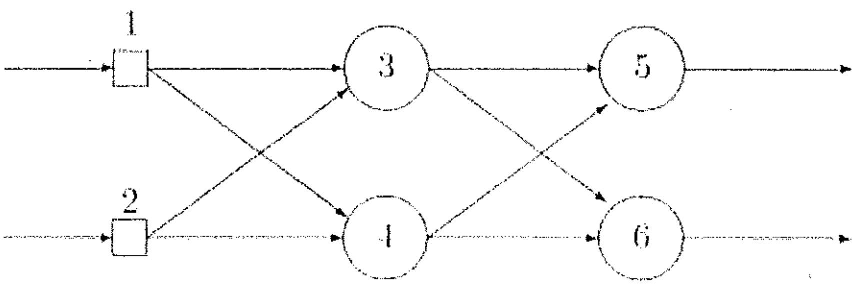

Figure Q6

A weight on connection between nodes i and j is denoted by w_{ij}, such as w_{13} is the weight on the connection between nodes 1 and 3. The following table lists all the weights in the network:

$w_{13} = -2$	$w_{35} = 1$
$w_{23} = 3$	$w_{45} = -1$
$w_{14} = 4$	$w_{36} = -1$
$w_{24} = -1$	$w_{46} = 1$

Each of the nodes 3, 4, 5 and 6 uses the following activation function:

$$\varphi(v) = \begin{cases} 1 & \text{if } v \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

where v denotes the weighted sum of a node. Each of the input nodes (1 and 2) can only receive binary values (either 0 or 1). Calculate the output of the network (y5 and y6) for each of the input patterns. [15 marks]

Q7.

You have been asked to design an environmental protection information system for protecting the city of Lilliput especially against oil spillage and the contamination of the water systems that form the aquatic environment of the city.

Location of Containment: The aquatic environment for Lilliput where oil spillage can take place comprises: the open waters of the Degul Sea (DS) together with its 3 mile (z3) and 12 mile (z12) zones regarded as Lilliput aquatic territory under international law. Furthermore, oil spills can also take place in the various canal systems in Lilliput (LCS), in the Lilliput harbor (LH), and in the refueling (RD) and loading docks (LD) in the harbor.

Agencies Involved: The protection of the environment involves multiagency overlapping jurisdictions. The Environmental Protection Agency (EPA) has the responsibility for the open sea and the 12-mile zone. The Port of Lilliput Authority (PLA) has the sole responsibility for the Harbor and the docks; neither the EPA nor the Lilliput Police (LP) can enforce environmental protection laws in the Harbor and the docks. The Lilliput City Council (LCC) is responsible for the canals. The Fire Brigades Authority (FBA) is obliged to put out fires and remove chemical hazards, including oil spills, but has no equipment to work on the open seas.

Remedial Actions: The environmental protection laws have the following civil and criminal remedies for the plaintiffs, usually one of the five authorities mentioned above:

i. the polluter can be issued with a warning by the EPA;
ii. the polluter pays for the clean-up operation as levied by the FBA, the Port of Lilliput Authority, and the Lilliput Police;

iii. the polluter is fined by the FBA;

iv. the polluter can be given a prison sentence if and only if the Lilliput Police registers a case against the polluter and successfully prosecutes the polluter.

(a) The three domains that will be used in modelling the aquatic environment protection system are: location of containment (Ω_{Loc}), agencies involved (Ω_{Age}), and remedial actions (Ω_{Rem}).
Describe the members of the term sets related to each of the three domains based on the description of the aquatic environment protection system for oil spills. [5 marks]

(b) The universe of discourse for the oil spill related environmental protection system is

$$\Omega = \Omega_{Loc} * \Omega_{Age} * \Omega_{Rem}$$

Describe how many states or elementary events that are permitted a priori. [5 marks]

(c) Extract at least 5 rules from the description of the system comprising two domains at a time. [5 marks]

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