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(University of Choice)

MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY (MMUST)

MAIN CAMPUS

UNIVERSITY EXAMINATIONS
2021/2022 FIRST SEMESTER EXAMINATIONS

FOR THE DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL AND COMMUNICATION ENGINEERING

COURSE CODE: ECE 513
COURSE TITLE: NON-LINEAR AND MULTIVARIABLE CONTROL

DATE: FRIDAY, APRIL, 29TH, 2022. TIME: 3:00 – 5:00 PM

INSTRUCTIONS TO CANDIDATES

- *This Paper Consists of **FIVE** Questions.*
- *Attempt Question **ONE** and **TWO** other Questions (Do not attempt more than expected).*
- *Allow **ONE** hour for Question **ONE** and another **ONE** hour for **TWO** other Questions.*
- *Question **ONE** carries **30 MARKS** and all other Questions carry **20 MARKS** each.*
- *A **BONUS** will be awarded for clean and well-organized work.*
- *Candidates are reminded to **STRICTLY** adhere to the **Examination Rules and Regulations.***
- ***REQUIRED:** Answer Booklet and Calculator.*

QUESTION ONE (COMPULSORY) (30 MARKS)

1. State at least 4 differences between linear and nonlinear systems. **[4 Marks]**
2. Differentiate the following types of nonlinearities using appropriate examples.
   i. Inherent nonlinearities and intentional nonlinearities
   ii. Static nonlinearities and dynamic nonlinearities
   iii. Functional nonlinearities and piece-wise nonlinearities. **[4 Marks]**
3. The response of a system is $y = ax^2 + e^{bx}$. Test whether the system is linear or nonlinear. **[4 Marks]**
4. State at least two disadvantages of linearization to solve non-linear systems. **[2 Marks]**
5. A 2nd order system is represented by $\dot{x} = Ax$. Where, $A = \begin{bmatrix} -1 & 1 \\ -2 & -4 \end{bmatrix}$ using Lyapunov theorems determine the stability of the system at the origin. **[4 Marks]**
6. Derive the describing function of a simple dead zone **[4 Marks]**
7. State the Aizerman's and Kalman's conjecture. **[4 Marks]**
8. Discuss the terms stability in the large and stability in the small **[4 Marks]**

QUESTION TWO (20 MARKS)

1. Using phase plane diagrams, differentiate between the following:
   i. Stable node and unstable node
   ii. Stable focus and unstable focus
   iii. Saddle point and vortex **[6 Marks]**
2. A nonlinear second order servo is described by the equation below

$$\ddot{e} + 2\zeta\omega_n\dot{e} + 2\omega_n e + e^2 = 0$$

   Where $\zeta = 0.25$, $\omega_n = 1$ rad/sec.
   i. Find all the singularities of the system
   ii. Classify all singularities
   iii. Sketch the phase portrait in the neighborhood of the equilibrium points **[8 Marks]**
3. Consider a nonlinear system given by $\ddot{y} + \dot{y} + y = 0$. Construct the phase trajectory, using the method of Isoclines. Choose slope as $N = \{-4, -3, -2, -1, 0, 1, 2, 3\}$. **[8 Marks]**

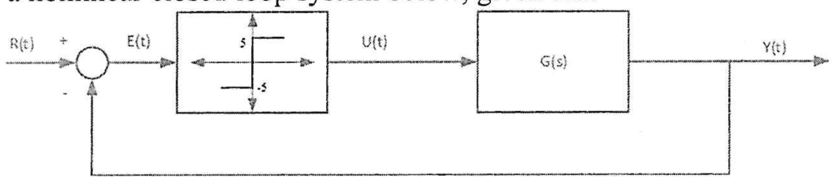
QUESTION THREE (20 MARKS)

1. What are the desirable characteristics of the nonlinear element while performing a describing function analysis? **[4 Marks]**
2. Differentiate between harmonic linearization and local linearization **[2 Marks]**
3. An input $x(t)$ and an output $y(t)$ of a nonlinear system are related through a nonlinear differential equation. Find the describing function of the system.

$$y = x^2\frac{dx}{dt} + 2x$$

[6 Marks]

4. Consider a nonlinear closed loop system below, given that



$$G(s) = \frac{1}{s(1+s)(s+6)}$$

   i. Determine if a limit cycle exist
   ii. if so determine if the limit cycle is a sustained oscillation
   iii. find the amplitude and frequency of the limit cycle. **[8 Marks]**

QUESTION FOUR (20 MARKS)

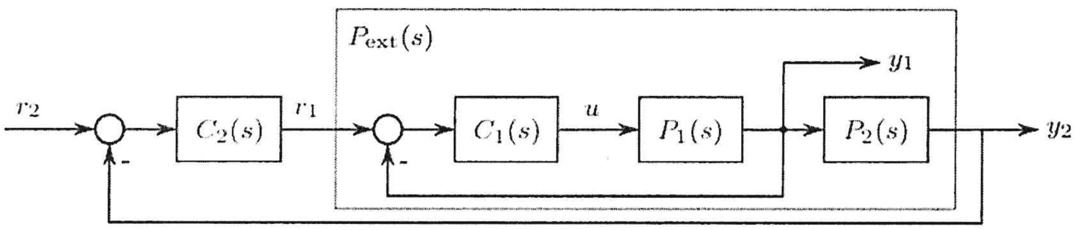
1. Discuss stability with reference to Linear Time Invariant systems **[2 Marks]**
2. Discuss the following terms using appropriate equations and drawings
   i. Lyapunov stability
   ii. Asymptotic stability
   iii. Quasi-asymptotic stability **[6 Marks]**
3. Given a scalar function $V(x) = 4x_1^2 + 2x_2^2 + x_3^2 + 2x_1x_2 + x_2x_3 + 2x_1x_3$ represent it in quadratic form and based on Sylvester's Theorem determine its definiteness. **[6 Marks]**
4. For the system described by the equation below, determine the equilibrium point and check for its stability using Lyapunov's stability theorem.

$$\dot{x}_1 = -x_1 - x_2(x_1^2 + x_2^2)$$
$$\dot{x}_2 = x_2 - x_1(x_1^2 + x_2^2)$$

[6 Marks]

QUESTION FIVE (20 MARKS)

1. State and explain Popov's hyperstability theorem. **[2 Marks]**
2. Discuss at least two nonlinear control design methods **[6 Marks]**
3. The control system of a SISO system is given below



Where the plant P_1 is given as $P_1 = \frac{1}{s+1}$ and the inner controller C_1 is given as $C_1(s) = 5$. To design the outer controller C_2, calculate the transfer function of the extended plant P_{ext} which includes the inner control loop and P_2, where $P_2 = \frac{1}{5s+1}$.
[4 Marks]

4. Consider a system described by a function

$$\dot{x} = -x - z - 2y$$
$$\varepsilon\dot{y} = -2y + tan(z)$$
$$\delta\dot{z} = -z - arctan(x^3 - y)$$

where $0 < \delta \ll \varepsilon$ are small parameters. Use singular perturbation to show that the origin is exponentially stable. **[8 Marks]**