Name: _____ Roll no.:_____

BSc(CSc),BTech. (Mech. Chem.): Semester XI

Subject Name: Mobile Robots Let's Build One! End Term Exam (Winter Sem .:2025); Marks:15 , Wt.:30 %

ENR 508 **April 28, 2025, Monday, 02.00 PM – 03.30 PM**

Instructions:

1. **Students from both CSc and CSE streams may answer the Question 8.**
2. **Figures to the right indicate full marks.**
3. **All acronyms and symbols carry their standard meanings.**
4. **Assume suitable data wherever necessary and clearly state your assumptions.**
5. **Write answers in sequence and clear handwriting.**
6. **Return the question paper and all rough work along with your answer sheet.**

Q-1. State the difference between open-loop and closed-loop control systems with examples. [2]

Q-2. Explain briefly what happens when the proportional gain in a PID controller is too high. [1]

Q-3. Let's assume that we have an Aldebaran Nao. In the manual, the nonlinear dynamics of an arm joint controlled by torque input are: [3]

$\dot{\theta} = \omega;\ \dot{\omega} = -\sin\theta - 0.5\omega + u$



Where:

- θ= angular position
- ω = angular velocity
- u = input torque

a) Linearise the system around the equilibrium point $(\theta = 0, \omega = 0, u = 0)$
b) Write the linearised system in state-space form.
c) Briefly explain the meaning and impact of linearisation in the context of control design for mobile robots.

Q-4. Consider a second-order Linear Time-Invariant (LTI) system described by the differential equation: [2]

$\ddot{y}(t) + 4\dot{y}(t) + 3y(t) = 2u(t)$

Where:

- $y(t)$ is the system output
- $u(t)$ is the input

Convert the system to **state-space form** by choosing appropriate state variables.

Q-5. Consider the nonlinear dynamic model of a mobile robot arm with two state variables: [2]

$$\dot{x}_1 = x_2\cos(x_1);\ \dot{x}_2 = \sin(x_1) + u$$

Where:

- x_1 is the joint angle
- x_2 is the angular velocity
- u is the input torque

a) Express the system in vector form: $\dot{x} = f(x, u)$
b) Compute the Jacobian matrix A, and matrix B. What are A and B matrices?
c) Evaluate the Jacobian matrices at the equilibrium point.
d) Write the linearised system in state-space form

Q-6. A mobile robot is required to follow a straight path by maintaining its heading angle θ at zero. A PID controller is used to minimise the heading error $e(t) = \theta_{desired}(t) - \theta(t)$ [2]

Where:

- $K_p = 2.0;\ K_i = 1.5;\ K_d = 0.5$
- The error function is $e(t) = sin(t)$
- Assume the initial error and its derivative are zero at $t = 0$

a) What is the PID controller equation?
b) Derive the expression for the control signal, $u(t)$.
c) Calculate the control input. $u(t)$ at time $t = \pi/2$.
d) What might happen if K_d is too high? Discuss system response and physical robot behaviour.

Q-7. A mobile cleaning robot operates in two behaviours: [3]

1. Moving behaviour:

   - The robot moves forward at 0.5 m/s.
   - It switches to Charging Mode when its battery level falls below 20%.

2. Charging behaviour:

   - The robot stays still and charges its battery at 10% per minute.
   - It switches back to Moving Mode when the battery level reaches 100%.

a) List the **discrete states** of the system.
b) What are the **continuous variables**?
c) Write the **conditions (guards)** for transitions between modes.
d) Sketch simple hybrid automata showing the two modes and transitions.

Q-8. *(Optional for CSc/CSE in place of any 2-mark question)* [2]

- What is SLAM?
- Explain the two probabilistic approaches for optimisation.
- Name two ML-based optimisation techniques, and give some examples for each.

All the best
