SNS COLLEGE OF TECHNOLOGY

(An Autonomous Institution)

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COIMBATORE-641 035, TAMIL NADU

B.E/B.Tech - Internal Assessment - III

Academic Year 2024-2025 (Even Semester)
Fourth Semester

Biomedical Engineering
23BMT205 – Biocontrol System

Answer Key

Time: $1\frac{1}{2}$ Hours Maximum Marks: 50

PART – A ($5 \times 2 = 10$ Marks)

1. **Differentiate distributed parameter and lumped parameter models.**

   - **Lumped Parameter Models**: Assume system properties (e.g., pressure, flow) are uniform within a compartment, simplifying analysis with ordinary differential equations. Used for systems like cardiovascular models where spatial variations are negligible. (1 mark)
   - **Distributed Parameter Models**: Account for spatial variations, using partial differential equations to describe properties (e.g., blood flow along a vessel) that change over distance. More complex but accurate for large, heterogeneous systems. (1 mark)

   [Bloom's: APP, CO4, Total: 2 Marks]

2. **Illustrate the physiological role of the pulmonary-cardiovascular interaction during stress.**

   - During stress, the pulmonary system increases ventilation to supply more oxygen. (1 mark)
   - The cardiovascular system responds by elevating heart rate and cardiac output, enhancing blood flow to lungs and muscles, ensuring adequate oxygen delivery and CO_2 removal, mediated by the autonomic nervous system and baroreceptors. (1 mark)

   [Bloom's: UND, CO4, GATE 2023, Total: 2 Marks]

3. **How is negative feedback embedded in physiological systems?**

- Negative feedback maintains homeostasis by counteracting deviations. (1 mark)
- Example: In blood pressure regulation, baroreceptors detect a rise in pressure, signaling the brain to reduce heart rate and dilate vessels, bringing pressure back to normal. (1 mark)

[Bloom's: UND, CO5, Total: 2 Marks]

4. **Infer the use of frequency response in evaluating baroreceptor-mediated circulatory control.**

- Frequency response analysis assesses how baroreceptors respond to oscillatory changes in blood pressure, quantifying system dynamics (e.g., gain, phase shift). (1 mark)
- It evaluates control stability and speed, aiding in understanding heart rate variability and designing cardiovascular devices. (1 mark)

[Bloom's: APP, CO5, GATE 2022, Total: 2 Marks]

5. **Draw the Block diagram of neuromuscular reflex model.**

- **Components**: Stimulus → Muscle Spindle (sensor) → Spinal Cord (controller) → Motor Neurons → Muscle (actuator) → Feedback to Muscle Spindle. (1 mark for correct sequence)
- **Description**: Stimulus (e.g., muscle stretch) is detected by the spindle, processed by the spinal cord, triggers muscle contraction via motor neurons, and spindle monitors resulting length for feedback. (1 mark for explanation)

[Bloom's: UND, CO5, Total: 2 Marks]

PART – B ($2 \times 13 = 26$ Marks)

1. **(a) Develop a lumped parameter model of the cardiovascular system and explain with relevant equations.**

- **Model Development**: A lumped parameter model treats the cardiovascular system as compartments (heart, arteries, veins) with properties like resistance (R), compliance (C), and inertance (L). (4 marks)
- **Components**:
  - Heart as a pump generating pressure. (2 marks)
  - Arteries and veins as compliant vessels ($C = \Delta V/\Delta P$, where V is volume, P is pressure). (2 marks)
  - Resistance to flow ($R = \Delta P/Q$, where Q is flow rate). (2 marks)
- **Equations**:

- Flow: $Q = (P_{\text{arteries}} - P_{\text{veins}})/R$ (1 mark)
- Compliance: $P = V/C$ (1 mark)
- Continuity: $dV/dt = Q_{\text{in}} - Q_{\text{out}}$ (1 mark)

- **Explanation**: This model simulates blood flow and pressure dynamics, assuming uniform properties within each compartment, used to study cardiac output and blood pressure regulation. (2 marks)

[Bloom's: ANA, CO4, Total: 13 Marks]
(OR)
(b) Propose a system using physiological models to regulate glucose in an ICU setting. Evaluate its response to patient variability.

- **System Proposal**: A closed-loop glucose control system:
  - **Sensor**: Continuous glucose monitor (CGM) measures blood glucose. (2 marks)
  - **Controller**: Algorithm (e.g., PID control) calculates insulin dose. (2 marks)
  - **Actuator**: Insulin pump delivers dose. (2 marks)
- **Model**: Glucose-insulin dynamics (e.g., Bergman's minimal model):
  - $dG/dt = -p_1G - p_2X + D$, where G is glucose, X is insulin effect, D is disturbance (e.g., meal). (2 marks)
  - $dX/dt = -p_3X + p_4I$, where I is insulin concentration. (2 marks)
- **Evaluation**:
  - **Patient Variability**: Differences in insulin sensitivity, metabolism, and stress response affect G and X. (1 mark)
  - **Response**: System adjusts insulin in real-time, but delays or overcorrections may occur in patients with high variability (e.g., diabetes, sepsis). (1 mark)
  - **Robustness**: Tested via simulations for diverse patient profiles; stabilizes glucose, reduces nurse workload. (1 mark)

[Bloom's: ANA, CO4, Total: 13 Marks]

2. **(a) Design a feedback control system for the muscle stretch reflex and explain its potential applications in developing adaptive rehabilitation devices.**

   - **Design**:
     - **Input**: Muscle stretch (e.g., tendon tap). (2 marks)
     - **Sensor**: Muscle spindle detects length change. (2 marks)

- **Controller**: Spinal cord processes signal via alpha motor neurons. (2 marks)
- **Actuator**: Muscle contracts to resist stretch. (2 marks)
- **Feedback**: Spindle monitors muscle length, feeding back to spinal cord. (2 marks)
- **Model**: $G(s) = K/(s + a)$, where K is gain, s is Laplace variable, a reflects dynamics. (1 mark)

- **Applications**:
  - Used in adaptive rehabilitation devices (e.g., exoskeletons) to mimic natural reflex, assist movement in patients with paralysis. (1 mark)
  - Adjusts gain (K) based on patient progress, enhances therapy for stroke or spinal injury. (1 mark)

[Bloom's: ANA, CO5, GE, Total: 13 Marks]
(OR)
(b) Analyze the stability and response behavior of the Pupillary light reflex system under sudden changes in ambient lighting, with relevance to ophthalmic device calibration.

- **Analysis**:
  - **System**: Pupillary light reflex adjusts pupil size to light intensity. (2 marks)
  - **Input**: Sudden change in ambient light (e.g., bright flash). (1 mark)
  - **Sensor**: Retina detects light intensity. (2 marks)
  - **Controller**: Brain (via oculomotor nerve) processes signal. (2 marks)
  - **Actuator**: Iris muscles constrict/dilate pupil. (2 marks)
- **Stability**: System is stable if pupil size settles to a steady state; modeled as $G(s) = K/(s + a)$, where damping (a) prevents oscillations. (2 marks)
- **Response Behavior**: Rapid constriction (short time constant) to bright light, slower dilation in dim light; transient response may overshoot. (1 mark)
- **Relevance**: Informs ophthalmic device calibration (e.g., autorefractors) to account for reflex speed and variability in patients. (1 mark)

[Bloom's: ANA, CO5, GATE 2021, Total: 13 Marks]

PART – C ($1 \times 14 = 14$ Marks)

1. **(a) (i) Formulate a simplified model integrating pulmonary and cardiovascular systems during mild exercise.**

- **Model Formulation**:

- **Pulmonary System**: Increases ventilation rate (V) to supply oxygen; $V = f(P_{CO2}, P_{O2})$, where P_{CO2} and P_{O2} are partial pressures. (2 marks)
- **Cardiovascular System**: Heart rate (HR) and stroke volume (SV) rise to boost cardiac output (CO = HR × SV). (2 marks)
- **Integration**: Oxygen demand drives ventilation; CO delivers O_2 to tissues. (1 mark)
- **Equations**:
  * Ventilation: $dV/dt = k_1(P_{CO2} - P_{CO2,set}) + k_2(P_{O2,set} - P_{O2})$ (1 mark)
  * Cardiac Output: CO = HR × SV, where HR increases linearly with exercise intensity. (1 mark)

[Bloom's: ANA, CO4, Total: 7 Marks]
(a) (ii) Apply transient response analysis to a neuromuscular reflex model and explain in detail.

- **Model**: Stimulus (stretch) → Muscle Spindle → Spinal Cord → Motor-Neurons → Muscle → Feedback. (2 marks)
- **Transient Response**:
  - **Input**: Step change in muscle stretch. (1 mark)
  - **Response**: Muscle contracts rapidly; modeled as $G(s) = K/(s + a)$. (1 mark)
  - **Analysis**: Rise time (fast due to reflex speed), settling time (stabilizes length), possible overshoot if gain K is high. (2 marks)
- **Explanation**: Reflects quick correction to stretch, critical for posture; delays or oscillations indicate neural issues. (1 mark)

[Bloom's: ANA, CO5, Total: 7 Marks]
(OR)
(b) (i) Analyze the regulatory mechanisms affecting cardiac output in different pathological states.

- **Mechanisms**:
  - **Normal State**: Cardiac output (CO = HR × SV) regulated by autonomic system, baroreceptors adjust HR. (2 marks)
  - **Pathological States**:
    * **Heart Failure**: Reduced SV, compensatory HR increase, but CO drops. (1 mark)
    * **Hypertension**: Increased vascular resistance, heart works harder, CO may be normal or reduced. (1 mark)

- **Analysis**: Frank-Starling mechanism boosts SV with venous return; in pathology, impaired contractility or resistance alters CO. (2 marks)
- **Impact**: Guides treatment (e.g., vasodilators for hypertension, inotropes for heart failure). (1 mark)

[Bloom's: ANA, CO4, Total: 7 Marks]

(b) (ii) Evaluate the frequency response of circulatory control models and their implications in heart rate variability analysis.

- **Frequency Response**:
  - **Model**: Circulatory control via baroreceptors, $G(s) = K/(s + a)$. (2 marks)
  - **Analysis**: Gain (K) shows response strength to blood pressure oscillations; phase shift indicates timing. (2 marks)
- **Evaluation**: High-frequency response (0.15-0.4 Hz) reflects vagal activity, low-frequency (0.04-0.15 Hz) shows sympathetic control. (2 marks)
- **Implications**: Heart rate variability (HRV) analysis uses this to assess autonomic balance, diagnose stress or cardiac risk. (1 mark)

[Bloom's: ANA, CO5, Total: 7 Marks]

Total Marks: 50

Part A: 10 marks (5 questions, 2 marks each)

Part B: 26 marks (2 questions, 13 marks each)

Part C: 14 marks (1 question, 14 marks split as 7 + 7)