Final Examination Study Guide

INTRODUCTION TO ROBOTIC DESIGN

Programme: BENG Mechatronics
Credits: 3
Duration: 45 Hours
Assessment: Final Examination (50% of total grade)

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1. Exam Overview

The final examination will assess your understanding of all four units, with an emphasis on:

- Robotic manipulators (modelling, control, kinematics, dynamics)
- Autonomous systems (SLAM, navigation, uncertainty, localization)
- LabVIEW programming (interfaces, control applications, real-time programming
- Advanced control for mobile robots (trajectory generation, locomotion, path-planning)

Exam Structure (Suggested):

- Multiple Choice Questions (20%)
- Problem Solving/Calculations (30%)
- Short Answer/Definitions (20%)
- Long Answer/Essay-style (30%)

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2. Topics by Unit

UNIT 1 – Robotic Manipulators
- Actuators and sensors
- Kinematics and path planning
- Basic dynamics
- Multivariable and advanced control

UNIT 2 – Autonomous Systems
- Probability in autonomy
- Uncertainty propagation
- Map-based localization
- Mapping and SLAM
- Reactive navigation and path-planning

UNIT 3 – LabVIEW Development Environment
- Programming fundamentals
- Debugging and error handling
- GUI design and data presentation
- ELVIS hardware interfacing
- Real-time and structured programming

UNIT 4 – Advanced Control for Mobile Robots
- Sensors and coordinate systems
- Locomotion modelling (kinematics, dynamics, actuator control)
- From path-planning to trajectory generation

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- Trajectory generation algorithms
- Long-term navigation and advanced control

3. Learning Outcomes to Focus On

You should be able to:

- Derive equations of motion using **Lagrange formulation**
- Apply control and modelling techniques to other problems
- Understand SLAM, map-based localization, and uncertainty propagation
- Generate trajectories and use advanced control for navigation
- Model robot arms and design controllers
- Demonstrate **LabVIEW programming skills**
- Explain the link between advanced control and autonomy

4. Practice Questions

SECTION A: Multiple Choice (Sample)

1. Which of the following is the correct Lagrangian equation of motion for a conservative system?
   a) $\frac{d}{dt}\left(\frac{\partial L}{\partial q}\right) - \frac{\partial L}{\partial \dot{q}} = 0$
   b) $\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) - \frac{\partial L}{\partial q} = 0$
   c) $\frac{d}{dt}\left(\frac{\partial L}{\partial q}\right) + \frac{\partial L}{\partial \dot{q}} = 0$
   d) $\frac{\partial L}{\partial \dot{q}} - \frac{d}{dt}\left(\frac{\partial L}{\partial q}\right) = 0$
2. In SLAM, what does the “mapping” component do?
   a) Plans the robot’s path
   b) Builds or updates a representation of the environment
   c) Controls wheel velocities
   d) Removes sensor noise
3. A LabVIEW **Block Diagram** contains:
   a) The user interface
   b) Graphical source code (nodes and wires)
   c) Hardware configuration files
   d) Compiled machine code
4. Which locomotion type is most common in indoor mobile robots for flat surfaces?
   a) Legged
   b) Differential drive
   c) Tracked
   d) Aerial

5. Uncertainty propagation is important in autonomous systems because:
   a) Sensors are perfect
   b) Measurements have noise and errors accumulate over time
   c) Actuators have infinite resolution
   d) Mapping is always deterministic
6. A 6-degree-of-freedom robotic manipulator typically has:
   a) 6 actuators
   b) 6 links and 6 joints
   c) 6 sensors only
   d) Both a and b
7. In LabVIEW **real-time programming**, which is true?
   a) Only Windows can be used
   b) Deterministic loop timing is required
   c) No error handling is needed
   d) ELVIS cannot be used
8. The main difference between **path-planning** and **trajectory generation** is:
   a) Path-planning ignores obstacles
   b) Trajectory generation adds time and dynamics
   c) Path-planning uses only vision
   d) They are identical
9. Map-based localization requires:
   a) A known map and sensor observations
   b) No sensors
   c) GPS indoors
   d) Only wheel odometry
10. Reactive navigation means:
    a) The robot plans a global path first
    b) The robot responds directly to sensor inputs without extensive world model
    c) The robot uses deep learning
    d) The robot is teleoperated
11. The ELVIS system from National Instruments is primarily used for:
    a) 3D printing
    b) Interfacing analogue/digital hardware with LabVIEW
    c) Compiling Python code
    d) Motor manufacturing
12. A mobile robot's **kinematic model** describes:
    a) Forces causing motion
    b) Motion without considering forces
    c) Battery consumption
    d) Colour detection
13. In the Lagrange formulation, the Lagrangian L is defined as:
    a) $T + V$
    b) $T - V$
    c) $V - T$
    d) $\dot{T} - V$
14. Which algorithm is fundamental for a robot to map an unknown environment while simultaneously tracking its own position?
    a) PID control
    b) SLAM

c) Fast Fourier Transform
d) Kalman filtering only

15. Trajectory generation algorithms must ensure:
a) Only position continuity
b) Position and velocity continuity (and optionally acceleration)
c) Minimal memory usage
d) Maximum speed regardless of stability

SECTION B: Short Answer (8 questions, 2–4 lines each)

16. What is a **robotic manipulator**? Name its two main types of joints.
17. Why is probability used in autonomous systems?
18. In LabVIEW, explain the difference between a **While Loop** and a **For Loop**.
19. List three types of sensors used in mobile robots for localization.
20. What does **Lagrange formulation** allow us to derive, and why is it useful for multi-link robots?
21. Define **reactive navigation**. Give one advantage and one disadvantage.
22. What is the purpose of **real-time programming** in LabVIEW for robot control?
23. Explain the term **uncertainty propagation** using a robot moving forward with noisy wheel encoders.

SECTION C: Problem Solving/Calculations

(4 questions, show all steps)

24. **Lagrange – Two-link planar arm (simplified)**
Consider a 2-link planar manipulator with:
   - Link 1: mass m_1, length l_1, distance to centre of mass a_1
   - Link 2: mass m_2, length l_2, distance to centre of mass a_2
   - Joint angles θ_1, θ_2
   Kinetic energy $T = \frac{1}{2}m_1(a_1\dot{\theta}_1)^2 + \frac{1}{2}m_2[(l_1\dot{\theta}_1)^2 + (a_2\dot{\theta}_2)^2 + 2l_1a_2\dot{\theta}_1\dot{\theta}_2\cos(\theta_2)]$
   Potential energy $V = m_1ga_1\sin(\theta_1) + m_2g[l_1\sin(\theta_1) + a_2\sin(\theta_1 + \theta_2)]$.
   Derive the **torque equation for joint 1** using Lagrange: $\tau_1 = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}_1}\right) - \frac{\partial L}{\partial \theta_1}$.
   (Keep $\frac{\partial L}{\partial \theta_1}$ and $\frac{d}{dt}$ in symbolic form – no need to fully expand.)
25. **Differential drive kinematics**
A mobile robot has wheel radius $r = 0.075$ m and track width $L = 0.4$ m.
   - Left wheel angular velocity $\omega_L = 8$ rad/s
   - Right wheel angular velocity $\omega_R = 12$ rad/s
   Calculate:
   a) Robot linear velocity v (m/s)
   b) Robot rotational velocity ω (rad/s)
   c) Instantaneous radius of curvature $R = v/\omega$.
   d) If the robot needs to follow a straight line at 0.8 m/s, what should ω_L and ω_R be (assuming same sign)?

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26. **Uncertainty propagation example**
A robot moves forward with velocity $v = 0.5$ m/s (standard deviation $\sigma_v = 0.02$ m/s) for time $t = 10$ s (standard deviation $\sigma_t = 0.1$ s). Assume v and t are independent.
Distance $d = v \times t$.
Compute the **mean distance** and the **standard deviation** of distance using first-order error propagation:

$$\sigma_d = \sqrt{\left(\frac{\partial d}{\partial v}\sigma_v\right)^2 + \left(\frac{\partial d}{\partial t}\sigma_t\right)^2}$$

27. **LabVIEW – Real-time control**
You must design a LabVIEW VI that reads an ultrasonic sensor (analogue voltage 0–5V, 0V = 0 m, 5V = 3 m) and controls a DC motor speed via PWM (0–100% duty cycle). The desired distance setpoint is 1.5 m.
a) Write the **pseudocode** for a simple P-controller loop running at 100 Hz.
b) What would be the consequence if you used a normal While Loop without timing control on a Windows PC?

SECTION D: Long Answer / Essay (3 questions, choose 2)

28. **Advanced control and autonomy** (Unit 4)
Explain in detail the link between **path-planning** and **trajectory generation** for mobile robots. Why is trajectory generation essential for autonomous long-term navigation? Include the role of dynamic constraints (e.g., max velocity, acceleration). Provide a real-world example.
29. **SLAM and localization** (Unit 2)
Describe the **SLAM problem** and its importance in unknown environments. Explain the difference between **map-based localization** and **mapping**. How does uncertainty propagation affect SLAM? Name one algorithm often used to solve SLAM.
30. **LabVIEW and hardware interfacing** (Unit 3)
You are given an **ELVIS** workstation with an analogue input (AI0) and a digital output (DIO0). Write a detailed step-by-step explanation (including required LabVIEW structures, functions, and front panel elements) to:
   - Read a potentiometer as a setpoint for motor speed (0–5V).
   - Output a PWM signal to a motor driver via DIO0.
   - Display the measured speed and setpoint on a graph in real time.
   - Include error handling and a stop button.

Answer Key – Expanded Practice Questions

Section A (MCQ)

1. b
2. b
3. b
4. b
5. b
6. d
7. b
8. b
9. a
10. b
11. b
12. b
13. b
14. b
15. b

Section B (Short Answer)

16. A robotic manipulator is an articulated mechanical arm used for tasks like assembly or welding. Main joint types: revolute (rotary) and prismatic (linear).
17. Probability accounts for sensor noise, actuator errors, and environmental uncertainty, enabling robust decision-making.
18. While Loop repeats indefinitely until a condition is met; For Loop repeats a fixed number of iterations.
19. Wheel encoders, LIDAR, cameras, ultrasonic sensors, IMU (any three).
20. Lagrange formulation derives equations of motion from energy expressions. It is systematic for multi-link robots, avoiding complex force balance.
21. Reactive navigation: robot responds immediately to sensors (e.g., obstacle avoidance). Advantage: fast; Disadvantage: can get stuck or suboptimal.
22. Real-time programming ensures deterministic loop timing, critical for stable control loops and sensor data fusion.
23. Uncertainty propagation: small errors in wheel velocities cause growing position uncertainty over time (dead reckoning drift).

SECTION C: Problem Solving / Calculations (4 questions, show all steps)

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5. b
6. d
7. b
8. b
9. a
10. b
11. b
12. b
13. b
14. b
15. b

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24. position uncertainty over time (dead reckoning drift).

Section C (Problem Solving)

24.
Let $L = T - V$. For joint 1:

$$\tau_1 = \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}_1}\right) - \frac{\partial T}{\partial \theta_1} + \frac{\partial V}{\partial \theta_1}$$

Given T and V, compute partial derivatives symbolically (student should show expressions). No full expansion required.

25.
a) $v = \frac{r}{2}(\omega_R + \omega_L) = 0.0375 \times 20 = 0.75\, m/s$
b) $\omega = \frac{r}{L}(\omega_R - \omega_L) = (0.075/0.4) \times 4 = 0.1875 \times 4 = 0.75\, rad/s$
c) $R = v/\omega = 0.75/0.75 = 1.0\, m$
d) For straight line, $\omega = 0 \Rightarrow \omega_R = \omega_L = v/r = 0.8/0.075 = 10.667\, rad/s$

26.
Mean $d = 0.5 \times 10 = 5.0\, m$
$\frac{\partial d}{\partial v} = t = 10, \frac{\partial d}{\partial t} = v = 0.5$

$$\sigma_d = \sqrt{(10 \times 0.02)^2 + (0.5 \times 0.1)^2} = \sqrt{0.04 + 0.0025} = \sqrt{0.0425} \approx 0.206\, m$$

27.
a) Pseudocode:

```text
while stop button not pressed:
  read voltage AI0
  distance = voltage * (3/5)
  error = 1.5 - distance
  duty = Kp * error   (limit 0 to 1)
  set PWM output on DIO0 with duty
  wait 10 ms (100 Hz)
```

b) Without timing control, loop may run unpredictably fast or slow, causing unstable control and missed samples.

Section D (Long Answer – outline key points)

28. Path-planning gives a geometric route (waypoints). Trajectory generation converts waypoints into time-stamped positions, velocities, accelerations respecting robot limits (e.g., max speed, jerk). Essential for smooth, feasible motion, avoiding slippage or actuator saturation. Example: autonomous car planning a lane change must generate a smooth trajectory to avoid abrupt steering.
29. SLAM solves the chicken-and-egg problem: to map, you need a good pose estimate; to localize, you need a map. Uncertainty propagation occurs because both map and pose are uncertain. Common algorithm: Extended Kalman Filter (EKF) SLAM or GraphSLAM.
30. Student should describe:

- Use DAQ Assistant or low-level DAQmx functions.

- Front panel: stop button, potentiometer control, waveform chart.
- Block diagram: while loop with Wait (ms) for timing.
- Read AI0, scale to 0–100%.
- Generate PWM using a timed loop or simple counter/timer.
- Error handling (error cluster, case structure).
- Stop button to exit loop.

Additional Support

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