Control Engineering

(MEC524)

M. H. M. Ramli, haniframli@uitm.edu.my **PBL Assignment**

Problem-Based Learning Assessment: Path Following for a Differential Drive Robot

INDUSTRY CHALLENGE

Client: Automated Logistics Solutions (ALS)

Context: ALS has deployed a fleet of differential drive mobile robots in their manufacturing facility to transport components between workstations. These robots follow predefined paths but frequently encounter efficiency issues when:

- Carrying different payload weights between stations (0.5-3.0 kg)
- Transitioning between different floor surfaces (standard concrete to epoxy-coated sections)

Engineers have observed that robots often deviate significantly from their paths after picking up heavy components, and again when dropping them off. This reduces efficiency and occasionally causes delivery delays that impact production scheduling.

Your Mission: As ALS's newly hired robotics engineering team, you must analyze their robot control system and develop an improved solution that maintains accurate path following under varying payload conditions. Your solution will serve as a prototype for fleet-wide implementation.

LEARNING OBJECTIVES

After completing this PBL assignment, you will be able to:

- Apply theoretical knowledge of mobile robot kinematics and dynamics to real-world problems
- Quantify and analyze the effects of changing physical parameters on robot performance
- Design and implement adaptive control strategies for improved path following
- Evaluate control system performance using appropriate metrics and visualizations
- Communicate engineering solutions effectively through technical documentation

TASKS

PART 1: SYSTEM ANALYSIS (25%)

Start by analyzing the provided mobile robot simulation:

1. **Baseline Performance Assessment**:
    - o Run the existing simulation code with its three scenarios (simple motion, figure-8 path, kinematics vs. dynamics comparison)
    - o Document the robot's current performance metrics
    - o Generate baseline path following error graphs for reference

2. **Technical Understanding**:
   - Explain the mathematical models governing the robot's behavior:
     - Forward and inverse kinematics equations (with clear interpretations)
     - Dynamic model equations (explaining how they account for inertia and friction)
     - Control scheme implementation
   - Compare and contrast the kinematic and dynamic models using specific examples from the simulation
   - Create a clear diagram showing the information flow in the control system
   - Identify potential weaknesses in the current control strategy when faced with changing conditions

PART 2: SOLUTION DEVELOPMENT (40%)

Implement a complete solution to the payload-variation problem:

1. **Payload Simulation**:
   - Modify the code to simulate a robot picking up a 2.0 kg payload at the 1/4 point of the figure-8 path
   - Implement payload release at the 3/4 point of the path
   - Calculate and update all relevant dynamic parameters (mass, inertia, friction)
   - Create appropriate visualizations to highlight when/where payload changes occur

2. **Performance Analysis**:
   - Design a systematic testing protocol to quantify how payload changes affect:
     - Path following accuracy (maximum and average deviation)
     - Control effort (torque requirements)
     - Velocity profiles before, during, and after carrying the payload
   - Identify specific path segments/manoeuvres where performance degrades most significantly

3. **Engineering Explanation**:
   - Explain the underlying mechanical principles causing the performance changes
   - Reference specific equations from the dynamic model to support your explanation
   - Predict how performance would change with different payload masses (1.0 kg, 2.5 kg)
   - Discuss practical implications for real-world deployment

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PART 3: CONTROL SYSTEM ENGINEERING (35%)

Develop and validate an improved control solution:

1. **Controller Enhancement**: Choose ONE of the following approaches (justify your choice):
    - **Option A: Optimized Fixed-Gain Controller**
        - Develop a mathematical model to determine optimal fixed control gains
        - Implement these gains and test across multiple conditions
    - **Option B: Adaptive Control Strategy**
        - Design a controller that automatically adjusts based on detected conditions
        - Implement clear adaptation logic with appropriate constraints
        - Provide fail-safe mechanisms to prevent instability

2. **Comprehensive Evaluation**:
    - Compare your enhanced controller with the original using:
        - Path following accuracy (average and maximum error)
        - Stability analysis (error convergence rates)
        - Velocity profile smoothness
        - Control effort efficiency (total energy usage)
    - Test performance under at least three different scenarios:
        - Standard figure-8 path with payload changes

3. **Implementation Considerations**:
    - Discuss practical aspects of implementing your solution on real robots
    - Consider computational requirements, sensor needs, and robustness
    - Identify potential limitations and suggest mitigation strategies

DELIVERABLES

1. **Engineering Code Package**:
    - Well-commented MATLAB files implementing your solution
    - Readme file explaining code organization and execution instructions
    - Test scripts demonstrating key functionality

2. **Technical Report (maximum 12 pages)**:
    - Executive summary (key findings and recommendations)
    - System analysis (models, equations, control architecture)
    - Solution design and implementation
    - Performance evaluation with comparative analysis
    - Implementation considerations and limitations
    - References and appendices (as needed)

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ASSESSMENT CRITERIA

Your work will be evaluated based on:

Criterion	Description	Weight
Technical Understanding	Accurate explanation of robot kinematics, dynamics, and control principles	25%
Solution Design	Quality of implementation; appropriate parameter calculations; code organization and documentation	25%
Controller Performance	Effectiveness of your control solution; measurable improvement over baseline	25%
Engineering Analysis	Depth and quality of performance evaluation; insight into system behaviour; practical considerations	25%

PRACTICAL GUIDANCE

- Start by ensuring you thoroughly understand the existing models before making changes
- Create a testing framework that allows you to easily compare different control strategies
- When implementing the adaptive controller, start with simple adaptations and progressively add complexity
- Document each change and its impact - this will be valuable for your final report
- Remember to consider real-world constraints like computational efficiency and sensor limitations
- Connect your work to fundamental mechanical engineering principles - especially dynamics, control theory, and system modeling

RESOURCES
- Lecture notes on mobile robot kinematics and dynamics
- Simulation code base (provided)
- Reference papers on adaptive control strategies (provided)

Submission Deadline: 06/06/2025
Questions and Support: Please contact Dr. M. H. M. Ramli (haniframli@uitm.edu.my) for any clarifications.