Scilab case study project on

Dynamic Gain-Scheduled Adaptive Cruise Control Using Scilab

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Domain: Control System

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Abstract

This case study project implements Dynamic Gain-Scheduled Adaptive Cruise Control (ACC) using Scilab to enhance vehicle speed and distance regulation. A PD gain scheduling technique under a Linear Parameter Varying (LPV) framework adapts to changing vehicle mass and driving conditions. The system switches between Constant Cruise (CC) mode for velocity tracking and Spacing Control (SC) mode for maintaining a safe distance. Simulations using state-space modeling demonstrate smooth transitions, improved stability, and robust performance in varying traffic scenarios. Results confirm that gain scheduling enhances ACC effectiveness for real-world applications.

1. Introduction

Adaptive Cruise Control (ACC) is a crucial advancement in modern vehicle automation, designed to enhance driving safety and comfort by autonomously adjusting vehicle speed based on traffic conditions. Traditional ACC systems often struggle with varying road conditions, vehicle dynamics, and changing mass due to passenger or cargo variations. To address these challenges, this case study explores the implementation of Dynamic Gain-Scheduled Adaptive Cruise Control (ACC) using Scilab.

This study employs a Proportional-Derivative (PD) gain scheduling approach under a Linear Parameter Varying (LPV) framework, allowing the controller to dynamically adjust gains based on real-time driving scenarios. The host vehicle operates in two modes: Constant Cruise (CC) mode for velocity tracking and Spacing Control (SC) mode for maintaining a safe following distance. The system is simulated in Scilab to evaluate performance under different mass variations and lead vehicle behaviors. Results demonstrate that gain scheduling improves control adaptability, stability, and safety, making it a viable solution for real-world ACC applications.

2. Problem Statement

In current automotive systems, Adaptive Cruise Control plays a vital role by automatically managing the speed of the vehicle in coupling with the traffic flow. Most conventional ACC systems perform poorly because of different road conditions, particularly in terms of gradients, vehicle dynamics, and even the driver's preferences. Hence this simulated case study will analyse an ACC system using gain scheduling techniques within a Linear Parameter Varying (LPV) frame using Scilab.

3. Basic concepts related to the topic

3.1 Adaptive Cruise Control (ACC)

Adaptive Cruise Control (ACC) adjusts a vehicle's speed to maintain a safe distance from the lead vehicle. It operates in two modes:

- **Constant Cruise (CC) Mode**: Maintains a set speed when no obstacles are detected.
- **Spacing Control (SC) Mode**: Adjusts speed to maintain a safe following distance.

The safe distance is given by:

$$dsafe=Tgap\cdot vhost$$

where Tgap is the time gap and vhostv is the vehicle's speed.

3.2 Vehicle Dynamics and Control System

The host vehicle's longitudinal motion is modeled as:

$$\dot{x}=Ax+Bu$$

where:

- x_1 (position), x_2 (velocity)
- m (mass), b (damping), uu (control input).

The PD controller regulates acceleration using:

$$u=K_p e + K_d \dot{e}$$

where e is the distance error.

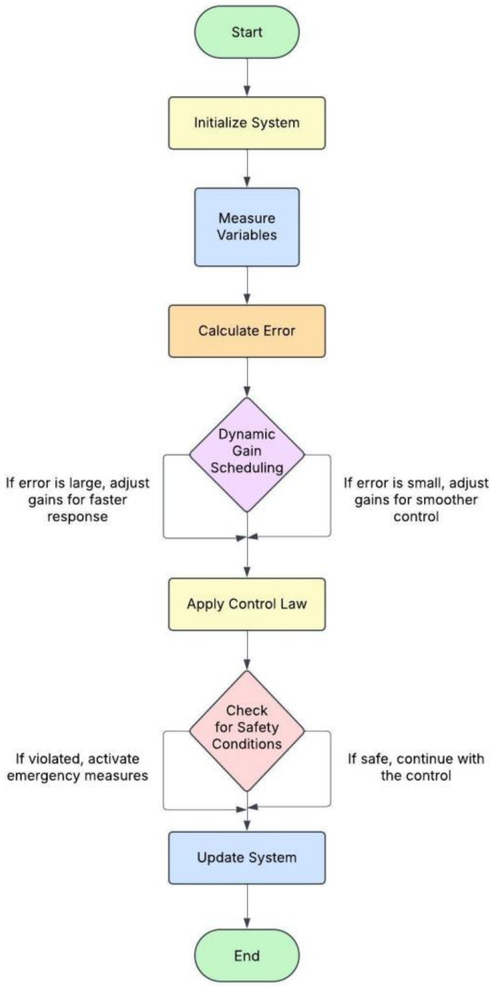
3.3 Gain Scheduling and LPV Framework

Gain scheduling dynamically adjusts controller gains (Kp,KdK_p, K_dKp,Kd) based on system parameters like mass and speed. The Linear Parameter Varying (LPV) framework updates state-space matrices in real time to maintain stability:

$$A(\rho) = \begin{bmatrix} 0 & 1 \\ 0 & -b/m(\rho) \end{bmatrix},\ B(\rho) = \begin{bmatrix} 0 \\ 1/m(\rho) \end{bmatrix}$$

where ρ represents mass or velocity.

4. Flowchart



5. Software used

OS: Windows Operating System

Scilab Version: Scilab – 2025.0.0

6. Procedure of execution

Step 1: Install Scilab

Ensure Scilab is installed on your system. You can download it from the official website: https://www.scilab.org.

Step 2: Open Scilab and Create a New Script

- Open Scilab.
- Go to File > New > Script to create a new .sce file.
- Copy and paste the main code into the script.

Step 3: Run the Code

- Save the script with a .sce extension (e.g., acc_simulation.sce).
- Click Execute > Execute File with Echo
- The script will prompt the user for input values.

Step 4: Provide User Inputs

Enter the required parameters when prompted:

User Input

Enter the time step (seconds): 0.1

Enter the total simulation time (seconds): 250

Enter the safe following distance (meters): 20

Enter the reference velocity (m/s): 20

Vehicle Mass for Each Phase

Mass for phase 1: 1820

Mass for phase 2: 2150

Mass for phase 3: 1820

Mass for phase 4: 2950

PD Controller Gains for Each Phase

Kp for phase 1: 1.0

Kd for phase 1: 0.1

Kp for phase 2: 1.2

Kd for phase 2: 0.15

Kp for phase 3: 1.0

Kd for phase 3: 0.1

Kp for phase 4: 1.5

Kd for phase 4: 0.2

Phase Durations

Duration for phase 1: 50

Duration for phase 2: 60

Duration for phase 3: 70

Duration for phase 4: 70

Step 5: Simulation Execution

The script will:

- Initialize system variables.
- Set up vehicle dynamics and control logic.
- Iterate through each phase, updating mass and PD gains dynamically.
- Simulate the lead vehicle's motion and apply control strategies.
- Store and visualize results.

Step 6: View and Analyze Output

Once the simulation completes, three graphs will be displayed:

- **Distance Error vs. Time** – Tracks how the host vehicle maintains a safe following distance.
- **Host Vehicle Velocity vs. Time** – Shows how the velocity is adjusted during cruise and spacing control modes.
- **Control Input vs. Time** – Displays the variation in throttle and braking actions over time.

Step 7: Debugging and Parameter Tuning

- If the simulation results are not as expected, re-run with different PD gains or phase durations.
- Ensure realistic inputs to avoid unrealistic outputs (e.g., extremely high or low vehicle mass).
- Modify gains to fine-tune the controller for better stability and responsiveness.

7. Result

The simulation results provide insights into the performance of the Dynamic Gain-Scheduled Adaptive Cruise Control (ACC) system under varying vehicle mass and lead vehicle behaviors. The following plots illustrate key aspects of system behavior, followed by an analysis of their significance.

7.1 Distance Error vs. Time

Plot Description:

- The distance error represents the difference between the actual and desired following distances.
- The plot shows how the ACC system adjusts speed to maintain the safe following distance across different phases.

Observations:

- The error initially fluctuates as the system stabilizes.
- As the lead vehicle accelerates or decelerates, the ACC system responds accordingly.
- Smooth error convergence indicates effective spacing control, ensuring safe driving conditions.

7.2 Host Vehicle Velocity vs. Time

Plot Description:

- This plot compares the host vehicle's velocity with the lead vehicle's movement patterns.
- The ACC system dynamically switches between Constant Cruise (CC) mode and Spacing Control (SC) mode based on relative distance.

Observations:

- In CC mode, the host vehicle maintains a steady reference speed.
- In SC mode, it adjusts velocity dynamically to keep a safe following distance.
- During mass changes (passenger pickups and drop-offs), speed variations remain stable due to gain scheduling.
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7.3 Control Input vs. Time

Plot Description:

- The control input plot represents the acceleration or braking force applied by the ACC system.
- It reflects smooth transitions between control actions based on relative distance and velocity changes.

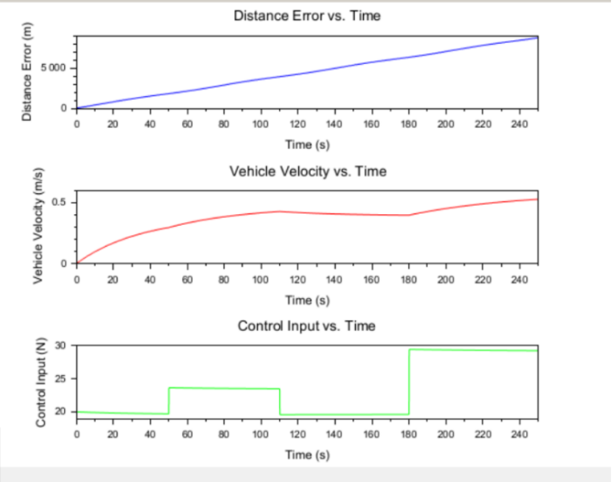
Observations:

- The system applies higher control effort during sudden braking or acceleration of the lead vehicle.
- The system successfully avoids overcompensation or instability, leading to robust performance.

7.4 Inferences from the Results

- **Effective Gain Scheduling:** The system dynamically adjusts controller gains based on vehicle mass changes, ensuring stable performance.
- **Smooth Mode Transitions:** The host vehicle seamlessly switches between CC and SC modes, adapting to real-time traffic conditions.
- **Improved Stability and Responsiveness:** The controller maintains a safe following distance while preventing sudden braking or acceleration.
- **Real-World Applicability:** The results confirm that Dynamic Gain-Scheduled ACC in Scilab can handle variable driving conditions, making it suitable for practical implementations in autonomous vehicles.

OUTPUT



8. References

1. **IEEE Paper:** “Adaptive Cruise Control With Gain Scheduling Technique Under Varying Vehicle Mass”

2. Relevant Scilab Documentation and Toolboxes for Control Systems.