Motion Analysis of Car Based on Angle of Accelerator Pedal

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Project Overview and Goals

The main goal was to relate the velocity of a 2022 Toyota Corolla to the angle of the accelerator pedal when starting from rest and maintaining first gear.

Data was collected using MATLAB Mobile sensor functionalities to measure pedal angle, car acceleration, position, velocity, and orientation.

The final goal of the project was to model the system accurately enough that the simulated velocity for a given pedal angle is within 10% of the actual velocity measured.

Creating a Model: Governing Equations

Forces Acting on a Car

$$F_r = mgC_r\text{sgn}(v)$$ — Rolling Friction

$$F_d = \frac{1}{2}\rho C_d A|v|v$$ — Drag Force

$$F_g = mg\sin(\phi)$$ — Gravity

$$F_e = \alpha\theta$$ — Engine Force

Components of the Disturbance Force

$$m\frac{dv}{dt} = \alpha\theta - mgC_r\text{sgn}(\text{v}) - \frac{1}{2}\rho C_d A|v|v - mg\sin(\phi)$$

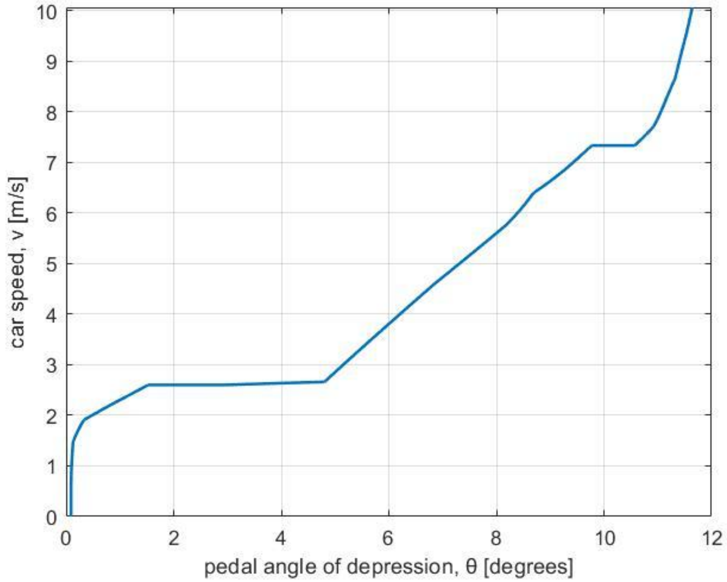
Governing Differential Equation for Car Motion

Creating a Model: State Space

Nonlinear System therefore $\dot{x} = f(x, u)$

$$\dot{x} = \begin{bmatrix} x_2 \\ \frac{1}{m}[\alpha u_1 - mgC_r x_2 - \frac{1}{2}\rho C_d A x_2^2 - mg\sin(u_2)] \end{bmatrix}$$

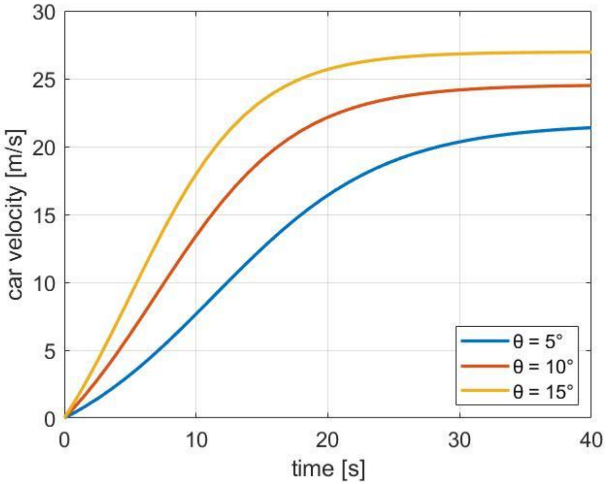
x_2 is the velocity of the car
u_1 is the angle of the pedal
u_2 is the angle of the road



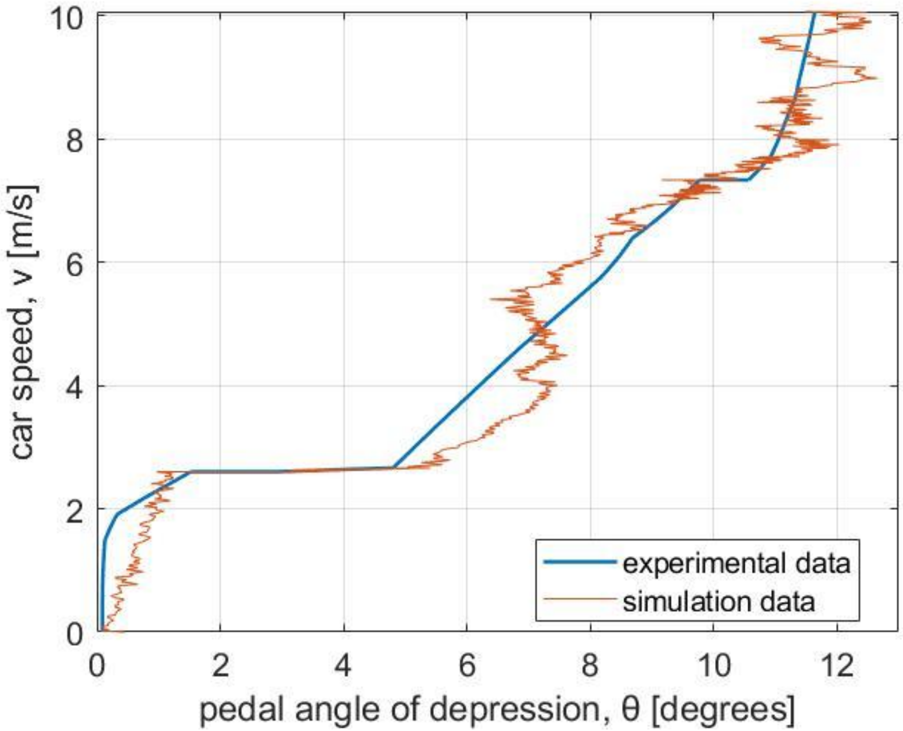
Creating a Model: Least Squares

$$g = Rp$$

$$g = \begin{bmatrix} ma_1 \\ ma_2 \\ \vdots \\ ma_{1140} \end{bmatrix} \qquad R = \begin{bmatrix} \theta_1 & v_1 & v_1^2 & \sin(\phi_1) \\ \theta_2 & v_2 & v_2^2 & \sin(\phi_2) \\ \vdots & \vdots & \vdots & \vdots \\ \theta_{1140} & v_{1140} & v_{1140}^2 & \sin(\phi_{1140}) \end{bmatrix} \qquad p = \begin{bmatrix} \alpha \\ -mgC_r \\ -\frac{1}{2}\rho C_d A \\ -mg \end{bmatrix}$$



Creating a Model: Comparison

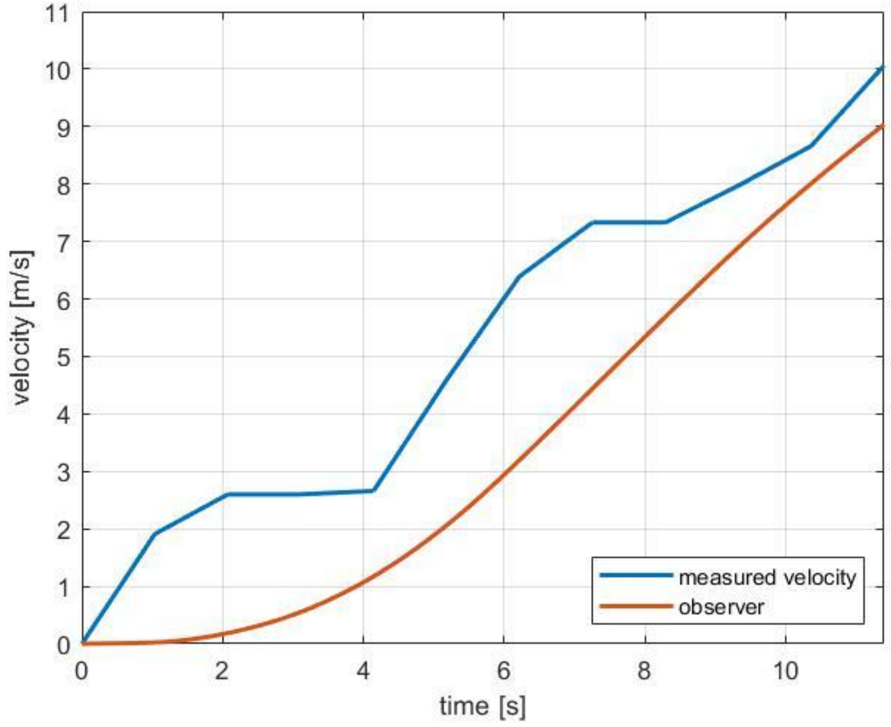


Designing an Observer:

- Linearized system about trajectory - measured data
- Taylor Series expansion for find linearized A and B matrices
- Evaluated at difference between state and trajectory
- Observer using new state:

$$\dot{\tilde{x}} = \begin{bmatrix} 0 & 1 \\ 0 & -gC_r - \frac{1}{m}C_d A(x - \hat{x}) \end{bmatrix} \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{\alpha}{m} \end{bmatrix} \tilde{u}$$

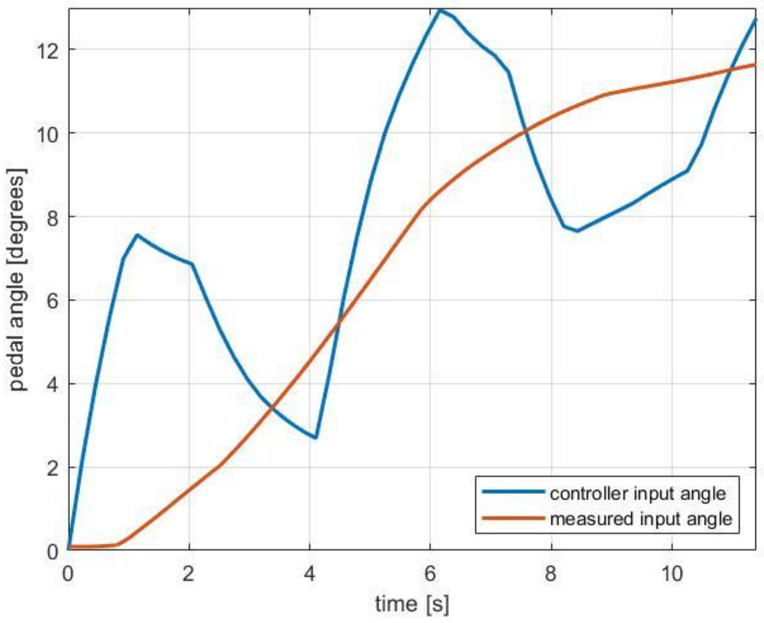
Designing an Observer:

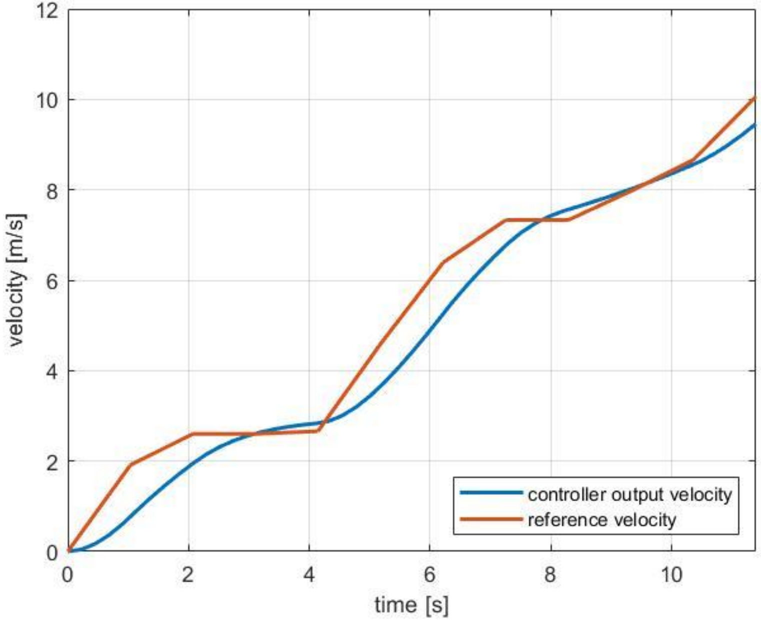


Controller Design

- System linearized around an average velocity of 5 m/s
- Controllability Matrix: $\omega = [B \;\; AB] \longrightarrow \text{rank}(\omega) = 1$, not controllable
- PI controller - bump test using $u = 1°$
- Using first order and time delay method:
    - $k_p = 5.46$
    - $k_i = 2.05$

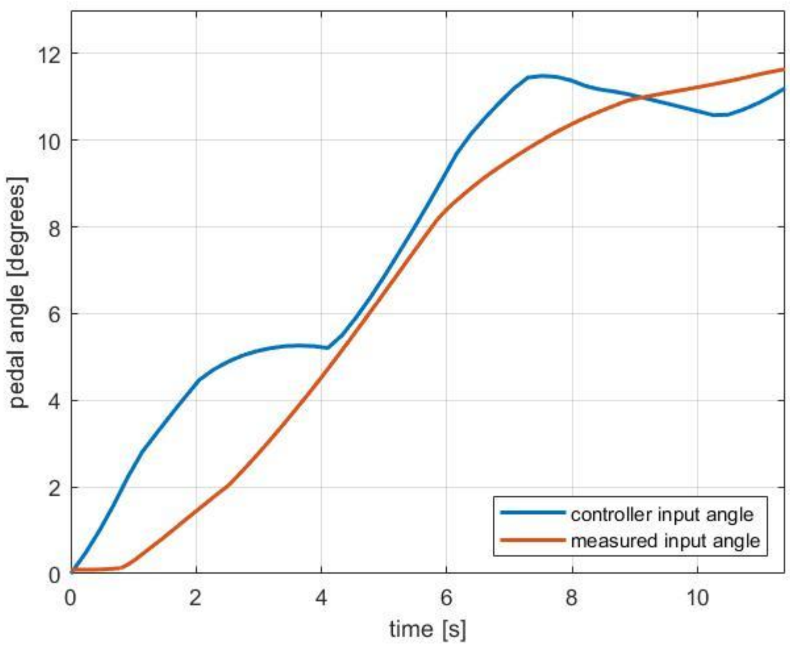
Controller Design: First Order and Time Delay

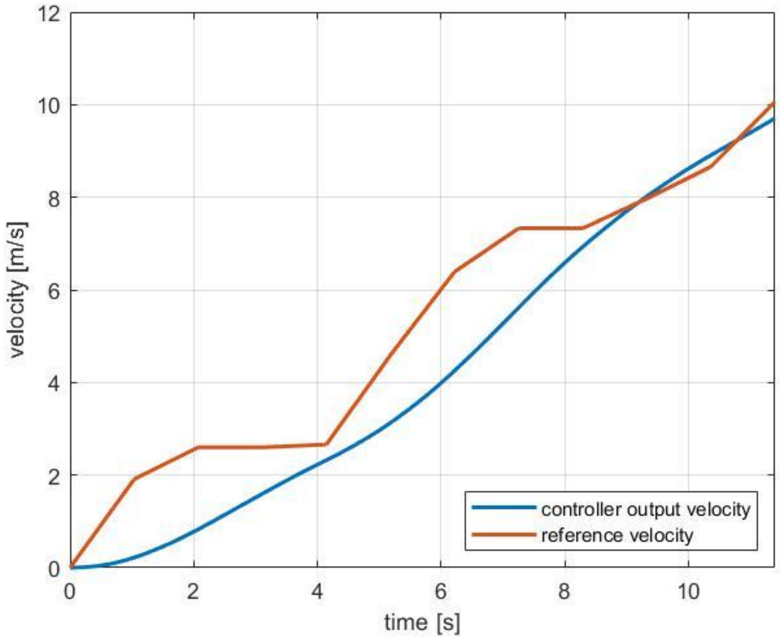




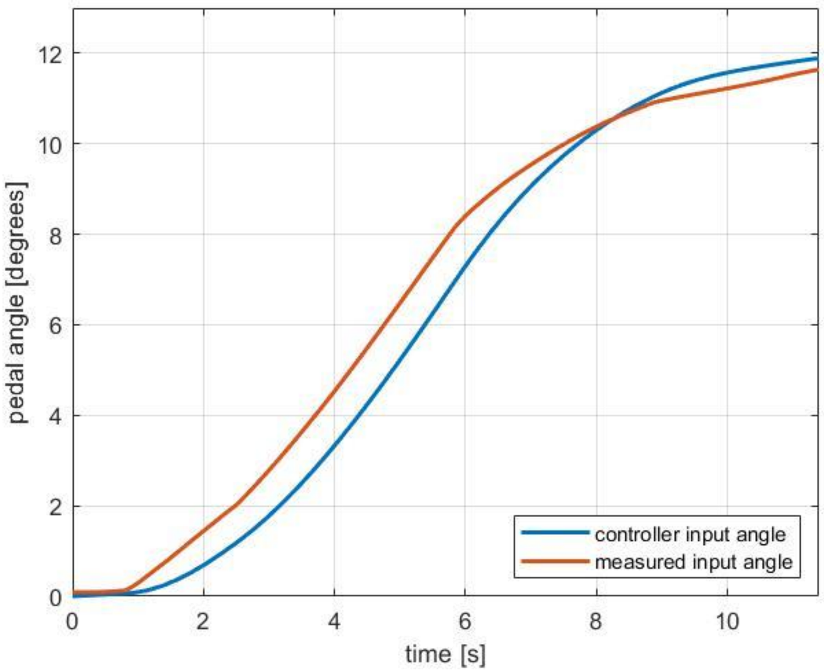
Controller Design: Alternate Gains

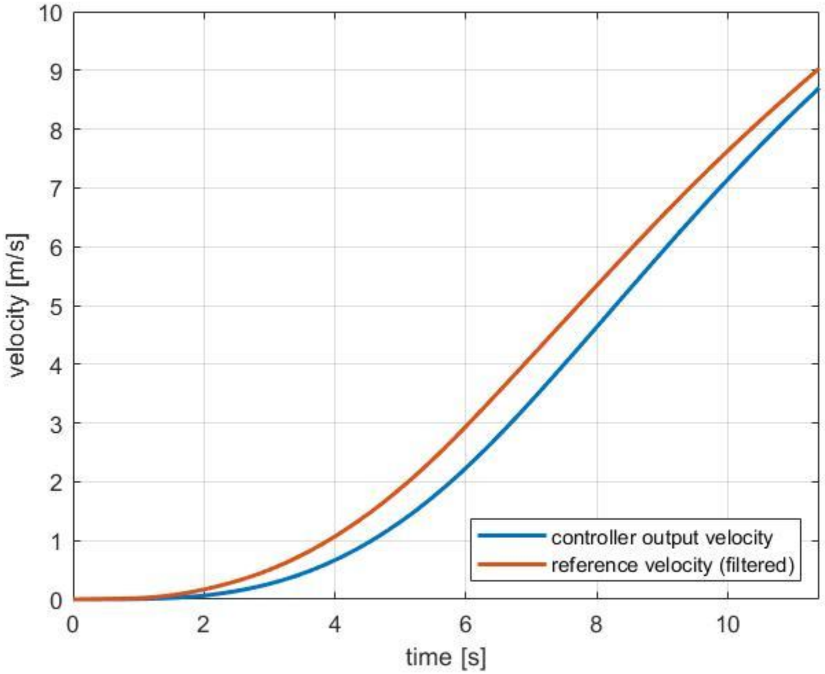
Reduced k_p to 1.2 for smoother input angle





Controller Design: Filtered Signal





Project Outcomes

- As controller approaches steady state, error falls within 10%

- At beginning of acceleration, error is greater than 10%

➔ Areas for improvement

Areas for Improvement

- Use varying instead of constant state space in linearization
- Improve velocity data collecting - use sensor with higher sampling frequency
- Find ways to improve model - make engine force more complex than direct correlation