Adaptive Cruise Control System Model

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Chapter 1

Part 1 (a)

1.1 Introduction

This part presents the derivation of a system model for an Adaptive Cruise Control (ACC) system. The model is based on the longitudinal dynamics of a vehicle and the dynamics of vehicle actuation. The model also considers the travel resistance which includes air drag, rolling resistance, acceleration resistance, and grading resistance.

1.2 Vehicle Dynamics Model

The longitudinal dynamics of a host vehicle is given by the equation:

$$m\dot{v}_h = ma_f - r_{travel} \tag{1.1}$$

where m is the vehicle mass, v_h is the vehicle speed, a_f is the traction force converted to acceleration, and r_{travel} is the travel resistance.

The dynamics of a vehicle actuation including engine, transmission, or brake has nonlinear characteristics. The input/output relationship of the actuation dynamics is described as an ordinary differential equation:

$$\dot{x}_f = f_{act}(x_f, u) \tag{1.2}$$

$$a_f = h_{act}(x_f) \tag{1.3}$$

where $x_f \in \mathbb{R}^{n_f}$, $u \in \mathbb{R}$ are respectively the state, the input of the actuation system. u is an acceleration command, i.e., a control input calculated by adaptive cruise controller. The output of the system is a_f.

The travel resistance r_{travel} contains several factors to resist its motion. A model of the resistive force is expressed as

$$r_{travel} = r_{air}v_h^2 + r_{roll}(\dot{v}_h) + r_{accel}\dot{v}_h + r_{grad}(\theta) \tag{1.4}$$

1.3 State-Space Model for ACC System

To build a plant model for the ACC system design, two state variables are defined: inter-vehicle distance following error $\Delta d = d - d_r$ and velocity following error $\Delta v = v_p - v_h$. The d_r is determined based on the constant time headway policy given by

$$d_r = T_{hw} v_h + d_0 \tag{1.5}$$

where T_{hw} is the constant time headway and d_0 is the stopping distance for safety margin.

Let us define the state variables of the plant as $x = [x_1 \quad x_2 \quad x_3^T]^T \in \mathbb{R}^{2+n_f}$ with $x_1 = \Delta d$, $x_2 = \Delta v$ and $x_3 = x_f$. Then, the state-space model is formulated as

$$\dot{x} = f(x, u) + Gv + Hw \tag{1.6}$$

$$y = Cx + Jv \tag{1.7}$$

where

$$f(x,u) = \begin{bmatrix} x_2 - T_{hw} x_3 \\ -h_{act}(x_f) \\ f_{act}(x_f, u) \end{bmatrix},$$

$$G = \begin{bmatrix} T_{hw}/m \\ 1/m \\ 0 \end{bmatrix},$$

$$H = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix},$$

$$C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

$$J = \begin{bmatrix} 0 \\ 0 \\ -1/m \end{bmatrix}$$

where $u \in \mathbb{R}$ and $y = [\Delta d \quad \Delta v \quad \dot{v}_h]^T \in \mathbb{R}^3$ are the input and output of the plant and $v = r_{travel}$ and $w = \dot{v}_p$ represents disturbances into the plant.