Fuzzy state and output feedback - control for vehicle lateral dynamics

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Abstract

Research related to the active control systems which improve the stability and the performance of vehicles in critical driving situations has experienced tremendous progress during the last years. Some of the systems have already been installed in passenger cars (ABS, ESP, ACC ...). However, these systems can be further improved using advanced estimation and control design methods [1]. The main goal is still to produce comfortable and safe vehicles. In this work, we study a quadratic stabilization conditions for Takagi–Sugeno (TS) fuzzy control systems, applied to the vehicle lateral dynamics. Stability conditions are represented in the form of LMIs. Hence, we will compare two types of control, to stabilize the dynamics of the vehicle. The first one is the control based on the output feedback, and the second one is the control based on the reconstructed state feedback.

The movement of the vehicle is defined by a set of translations and rotational movements, generally comprised of six main movements; but in this study, we will focus on the vehicle lateral dynamics 2DOF, which can be described by the following equations:

$$\begin{cases} m\dot{v}_y = m\psi v_y + 2(F_{yf} + F_{yr}) \\ I_z\dot{\psi} = 2a_r F_{yr} - 2a_f F_{yf} \end{cases} \quad (1)$$

The difficulty of obtaining a correct vehicle model is that the contact forces are difficult to measure and to model, using the method based on TS models proposed in [2], which are a very interesting mathematical representation of nonlinear systems, because they allow representing any nonlinear system, by a simple structure based on linear models.

The characteristics of the tires are generally assumed that the rear and front lateral forces are modeled with the magic formula as given in [3]. The overall forces are obtained by:

$$\begin{cases} F_{yf} = \sum_{i=1}^2 \mu(|\alpha_f|) C_{fi} \alpha_f(t) \\ F_{yr} = \sum_{i=1}^2 \mu(|\alpha_r|) C_{ri} \alpha_r(t) \end{cases} \quad (2)$$

where C_{fi} , C_{ri} are the front and rear tire cornering stiffness, respectively, which depend on the road friction coefficient and the vehicle parameters.

Using (2) to approximate the lateral cornering forces, the T-S model can be written in the following form:

$$\begin{cases} \dot{x}(t) = \sum_{i=1}^2 \mu(|\alpha_f|) [A_i x(t) + B_i u(t)] \\ y(t) = \sum_{i=1}^2 \mu(|\alpha_f|) [C_i x(t) + D_i u(t)] \end{cases} \quad (3)$$

As a conclusion, in this study, two types of stabilization conditions for vehicle lateral dynamics are presented. The first is for fuzzy state feedback stabilization problem and the second is for fuzzy static output feedback stabilization problem. The first control law gives results more relaxed. However, in real-world control problems, the states may not be completely accessible. In such situations, one needs to resort to output feedback design methods. Fuzzy static output feedback control is the most desirable since it can be implemented easily with low cost. Nevertheless, the fuzzy static output feedback stabilization problem of TS fuzzy systems is rarely investigated because it is quite hard theoretically for TS fuzzy systems but useful and very important in practice.

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Figure 1. Comparison between controlled system states (state & static output- feedback controls) and the uncontrolled

Keywords:

Fuzzy state; vehicle lateral dynamics; reconstructed state feedback; output feedback

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Figure 2. (a) Steering angle given by the driver, (b) Comparison between the response of the two types of control