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Fuzzy State and Output Feedback - Control for Vehicle Lateral Dynamics

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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 (Anti-lock Braking System, Electronic Stabilization Program, Adaptive Cruise Control ...). However, these systems can be further improved using advanced estimation and control design methods [1,2]. The main goal is still to produce comfortable and safe vehicles. In this work we study a quadratic stabilization conditions for Takagi–Sugeno (T–S) fuzzy control systems, applied to the vehicle lateral dynamics. Stability conditions are represented in the form of linear matrix inequalities (LMIs) [3]. Recently, based on T–S fuzzy model [4,5], there have appeared in the literature a great number of results concerning stability analysis and design for vehicle dynamics. In this study 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 (see Fig.1), generally six main movements; but in this study, we will focus just on the lateral dynamics of the vehicle (2DOF).

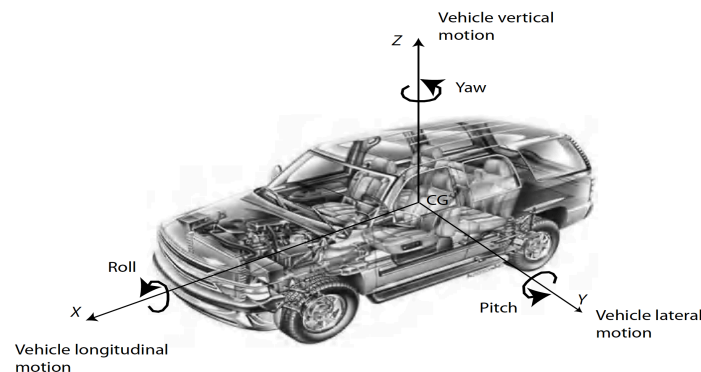


Figure 1. Vehicle Body Motions

The lateral and roll dynamics of the vehicle can be described by the following differential equations:

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

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 T-S models proposed in [5], which are a very interesting mathematical representation of nonlinear systems, because they allow representing any nonlinear system. Whatever its complexity, by a simple structure based on linear models interpolated by nonlinear positive, they have a simple structure presenting interesting properties that make them easily exploitable from the mathematical point of view.

The characteristics of the tires are generally assumed that the rear and front lateral forces are modeled with the magic formula as given in [8] by the following rules:

$$\begin{aligned} \text{If } |\alpha_f| \text{ is } M_{f1} \text{ then } F_{yf} &= C_{f1}\alpha_f \\ \text{If } |\alpha_f| \text{ is } M_{f2} \text{ then } F_{yf} &= C_{f2}\alpha_f \\ \text{If } |\alpha_r| \text{ is } M_{r1} \text{ then } F_{yr} &= C_{r1}\alpha_r \\ \text{If } |\alpha_r| \text{ is } M_{r2} \text{ then } F_{yr} &= C_{r2}\alpha_r \end{aligned} \quad (2)$$

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.

The overall forces are obtained by:

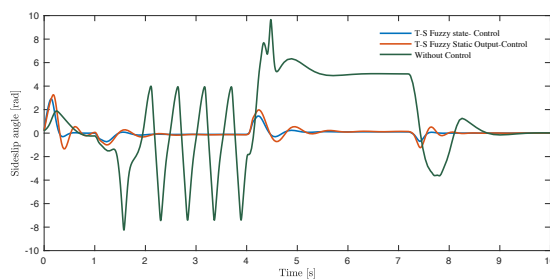
$$\begin{cases} F_{yf} = \sum_{i=1}^2 \mu_i(|\alpha_f|)C_{fi}\alpha_f(t) \\ F_{yr} = \sum_{i=1}^2 \mu_i(|\alpha_r|)C_{ri}\alpha_r(t) \end{cases} \quad (3)$$

Using (2) to approximate the lateral cornering forces in (1), the TS model can be written in the following form:

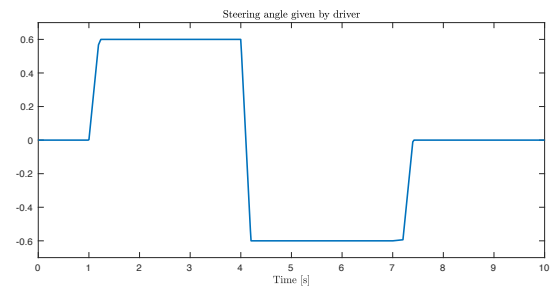
$$\begin{aligned} \dot{x}(t) &= \sum_{i=1}^r w_i(\theta(t))[A_i x(t) + B_i u(t)] \\ y(t) &= \sum_{i=1}^r w_i(\theta(t))[C_i x(t) + D_i u(t)] \end{aligned} \quad (4)$$

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, the second is for fuzzy static output feedback stabilization problem. The first control law gives results more relaxed. However, in real-word control problems, the states may not be completely accessible. In such situations, one needs to resort to output feedback design methods. Fuzzy static output

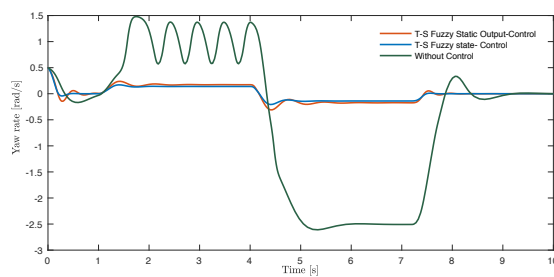
feedback control is the most desirable since it can be implemented easily with low cost. Nevertheless, the fuzzy static output feedback stabilization problem of T–S fuzzy systems is rarely investigated because it is quite hard theoretically for T-S fuzzy systems but useful and very important in practice.



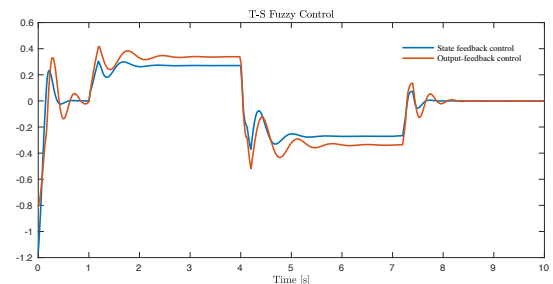
(a)



(a')



(b)



(b')

Figure 2. System states with different control types **Figure 3. (a') Steering angle, (b') both controls (state & static output-feedback controls)**

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