Available online at www.sciencedirect.com
SCIENCE DIRECT
Control Engineering Practice 14 (2006) 527–536
CONTROL ENGINEERING PRACTICE
www.elsevier.com/locate/conengprac

Model-based detection of critical driving situations with fuzzy logic decision making

Marcus Börner*, Rolf Isermann

Institute of Automatic Control, Darmstadt University of Technology, Landgraf-Georg-Str. 4, D-64283 Darmstadt, Germany

Received 29 July 2003; accepted 21 November 2004
Available online 26 January 2005

Abstract

A precise knowledge about the current driving condition is getting increasingly important for future driver assistance systems like global chassis control or collision avoidance systems for avoiding any critical driving situation. Moreover a precise knowledge about the driving situation can be used in testing, in evaluation, and for comparison of new passenger cars. A two degree of freedom model of vehicle lateral dynamics is used to derive a characteristic velocity stability indicator (CVSI). The CVSI is used to distinguish between different driving and stability conditions (i.e. understeering, oversteering, and neutralsteering). This forms the basis for a driving condition detection system with fixed thresholds. It is then extended to a detection system with fuzzy logic thresholds. The CVSI and the fuzzy systems are compared experimentally using (i) a slalom test drive on an icy road and (ii) a stationary circular test drive on a dry asphalt road.

Keywords: Vehicle dynamics; Parameter variation; Stability analysis; Critical driving situation; Classification; Fuzzy expert system

1. Introduction

Driver assistance systems have received increased attention as market demands have pushed for improved automotive safety. These systems are designed to aid the driver by preventing any unstable or unpredictable vehicle behavior. In conjunction with growing demands for better system performance and system reliability, online models, fault detection, and fault diagnosis methods can be favorably used in modern vehicles. Presently implemented online models are mostly performed by relatively simple algorithms, which do not work correctly in critical driving situations. One approach to cope with the problem encountered by these simple algorithms is to calculate the driving condition and stability, and from that to react with a reconfiguration or adaptation of models to the various situations.

Until now, the vehicles stability has been described by a constant characteristic velocity measured by steady-state circular test drives (Milliken & Milliken, 1995). A new approach to detect the stability of vehicles is shown in this contribution. Former work on this topic was based on fuzzy logic systems (Albertos & Börner, 1999). This approach was able to detect understeering, oversteering, and breaking away during cornering. The system required five measured input signals (steering input δ_{st}, lateral acceleration $\ddot{y}$, yaw rate $\dot{\psi}$, longitudinal acceleration $\ddot{x}$, and velocity v). Unfortunately, a sensor for the longitudinal acceleration is not equipped in standard vehicles and the signal has to be estimated from the wheel speed sensors.

Another deterministic approach for the online calculation of different driving situations based on the characteristic velocity (CVSI) was presented by Börner (2004). The advantage is the usage of only available sensor information. Now, a new fuzzy logic system

*Corresponding author. Tel.: +49 6151 16 4167;
fax: +49 711 1741 454.
E-mail address: risermann@iat.tu-darmstadt.de (R. Isermann).

0967-0661/$ - see front matter
doi:10.1016/j.conengprac.2004.11.008

based on a time-variant characteristic velocity stability indicator is discussed. The CVSI and fuzzy systems are then compared experimentally using a slalom test drive on an icy road and a stationary circular test drive on a dry asphalt road.

2. Vehicle model

For deriving the lateral dynamics, a coordinate system is fixed to the center of gravity (C.G.), (Fig. 1), and Newton's laws are applied

$$m\frac{v^2}{\rho}\sin\beta - m\dot{v}\cos\beta - F_{yF}\sin\delta = 0, \tag{1}$$

$$-m\frac{v^2}{\rho}\cos\beta - m\dot{v}\sin\beta + F_{yR} + F_{yF}\cos\delta = 0, \tag{2}$$

$$-J_z\ddot{\psi} + (F_{yF}\cos\delta)l_F - F_{yR}l_R = 0. \tag{3}$$

Roll, pitch, bounce, and deceleration dynamics are neglected to reduce the model to two degrees of freedom: the lateral position and yaw angle states. Further simplifications assume that each axle shares the same steering angles and that each wheel produces the same steering forces. The simplification (i.e., Mitschke, 1990)

$$\overbrace{\ddot{y} \cong \frac{v^2}{\rho} = v(\dot{\beta} + \dot{\psi}) \Rightarrow \beta = \int_0^t \left(\frac{\ddot{y}}{v} - \dot{\psi}\right)\mathrm{d}t}^{\text{Small angle } \beta \text{ (Linearization)}} \tag{4}$$

leads to the non-linear dynamic model. Isermann (2001) explains the resulting non-linear dynamic model known as the bicycle model in detail, see also Mitschke (1990) and Milliken and Milliken (1995):

$$\dot{\mathbf{x}}(t) = \mathbf{A}(t)\cdot\mathbf{x}(t) + \mathbf{b}(t)\cdot u(t)$$
$$\mathbf{y}(t) = \mathbf{C}(t)\cdot\mathbf{x}(t)$$

where,

$$\mathbf{x}(t) = \begin{bmatrix}\dot{y}(t)\\ \dot{\psi}(t)\end{bmatrix}, \quad \mathbf{y}(t) = \begin{bmatrix}\dot{y}(t)\\ \dot{\psi}(t)\end{bmatrix},$$

$$\mathbf{A}(t) = \begin{bmatrix} -\dfrac{c'_{\alpha F}(t) + c_{\alpha R}(t) + m\dot{v}(t)}{mv(t)} & \dfrac{c_{\alpha R}(t)l_R - c'_{\alpha F}(t)l_F}{mv(t)} \\ \dfrac{c_{\alpha R}(t)l_R - c'_{\alpha F}(t)l_F}{J_z v(t)} & -\dfrac{c_{\alpha R}(t)l_R^2 + c'_{\alpha F}(t)l_F^2}{J_z v(t)} \end{bmatrix},$$

$$\mathbf{b}(t) = \begin{bmatrix} \dfrac{c'_{\alpha F}(t)}{m i_{st}} \\ \dfrac{c'_{\alpha F}(t) l_F}{J_z i_{st}} \end{bmatrix}, \quad \mathbf{C}(t) = \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix},$$

$$u(t) = \delta_{st}(t). \tag{5}$$

Although the bicycle model is relatively simple, it has been proven to be a good approximation for vehicle dynamics when lateral acceleration is limited to 0.4 g on normal dry asphalt roads. Note that the velocity v and the cornering stiffness $c'_{\alpha F}$ and $c_{\alpha R}$ are assumed to be time-variant (Börner & Isermann, 2002).

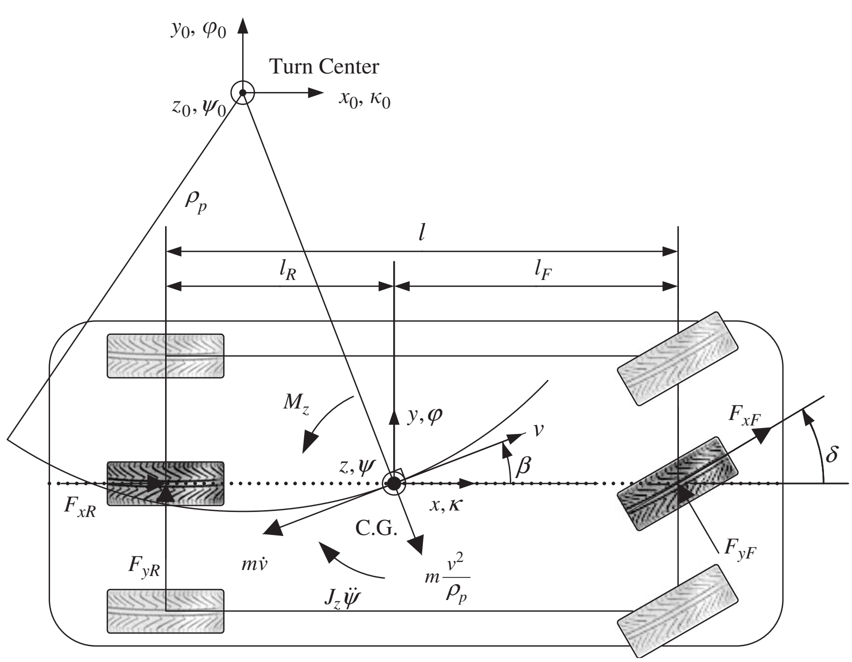

Fig. 1. Scheme for modeling the lateral vehicle behavior.