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Road surface condition identification approach based on road characteristic value

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Abstract

The real-time knowledge of road friction information has a significant role in vehicle dynamics control. In this paper, with the application of Burckhardt model, roads are classified into six types and a road identification approach based on "road characteristic value" is developed. Six kinds of road surface characteristic intervals which represent typical road characterization are proposed according to the closed area under the segment of road friction coefficient-slip ratio curve before a pre-defined slip ratio. In addition, a varying road monitoring and identification algorithm is proposed to identify varying road surface conditions, composing of an integral road surface identification approach with road characteristic value method. A vehicle dynamics model of 14 DOF including the excitation of road roughness is built, and the effectiveness of the approach is verified by the braking simulation tests on both a uniform friction coefficient uneven road and a variable friction coefficient uneven road. The simulation results show that the proposed approach can identify current road surface conditions effectively including road type, maximum road friction coefficient as well as optimal slip ratio, and it is robust to external disturbances. The application of road identification results in the optimal slip ratio control of vehicle electronic control braking system achieves good performance.

Keywords: Road surface identification; Road characteristic value; Variable road surface; Slip ratio control

1. Introduction

The real-time knowledge of road friction information is crucial in vehicle active safety electronic control systems such as vehicle electronic control braking systems, adaptive cruise control, vehicle stability control, collision-avoidance systems [1]. Tire behavior plays an important role in vehicle dynamics, and the main purpose of such systems is to regulate tire tangential force exerted by road surface [2]. Force between tire and road is restricted by the road friction conditions, therefore, vehicle active safety control strategy depends heavily on the use of the road surface friction condition. If real-time road friction information is automatically identified and corresponding vehicle control strategies are modified according to the identified results, it can significantly enhance vehicle's safety performance undoubtedly.

An vehicle Electric Control Braking System (ECBS) such as Anti-lock Braking System (ABS) based on target slip ratio control aims to make the real-time wheel slip ratio controlled at the slip ratio which maximum road friction coefficient corresponds to (optimal slip ratio) in order to make full use of the maximum road friction conditions and ensure the vehicle's directional stability during braking. Since different roads correspond to different optimal

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Nomenclature

z_{0i}	road roughness input	I_{xz}	sprung mass inertia product around X, Z-axis
z_i	vertical displacement of the wheel center	e	distance from vehicle mass center to vehicle roll axis and pitch axis
z_i'	suspension vertical displacement	l_f	distance from vehicle mass center to the front axle
a_x	vehicle longitudinal acceleration	l_r	distance from vehicle mass center to the rear axle
a_y	vehicle lateral acceleration	l	wheel base (m)
a_z	vehicle vertical acceleration	t_f	wheel tread (front) (m)
F_{xi}	tire longitudinal force ($i = 1, 2, 3, 4$)	t_r	wheel tread (rear) (m)
F_{yi}	tire lateral force ($i = 1, 2, 3, 4$)	d	wheel tread (m)
F_{zi}	tire normal force ($i = 1, 2, 3, 4$)	F_f	wheel rolling resistance (N)
M_{sq}	aligning moment	T_{fi}	wheel rolling resistance moment (N m)
m	total vehicle mass	F_w	air resistance (N)
m_s	sprung mass	R	tire dynamic radius (m)
m_i	unsprung mass ($i = 1, 2, 3, 4$)	ω_i	wheel rotational velocity ($i = 1, 2, 3, 4$) (rad/s)
k_i	tire radial stiffness ($i = 1, 2, 3, 4$)	T_{bi}	wheel brake force ($i = 1, 2, 3, 4$) (N m)
k_i'	suspension equivalent stiffness ($i = 1, 2, 3, 4$)	J_i	wheel rotational inertia ($i = 1, 2, 3, 4$)
c_i'	suspension equivalent damping coefficient ($i = 1, 2, 3, 4$)	I_x	sprung mass rotational inertia around X-axis
γ	vehicle yaw rate	δ	steering angle input (rad)
ϕ	vehicle body roll angle	h	height of vehicle's centre of gravity (m)
ρ	vehicle body pitch angle	h_f	distance from vehicle front axle roll center to the ground
μ	road friction coefficient	h_r	distance from vehicle rear axle roll center to the ground
s_{op}	optimal slip ratio		
$\mu_{\max}$	road surface maximum friction coefficient		
I_y	sprung mass rotational inertia around Y-axis		
I_z	sprung mass rotational inertia around Z-axis		

slip ratio, the control accuracy and control effect are not satisfactory if vehicle electronic controller adopts a fixed slip ratio as controller target. Therefore, we need to develop a road condition identification adaptive approach in order to improve the control quality of automotive electronic control braking system on different roads.

Electronic stability control (ESC) system controls the yaw rate of the vehicle to prevent skidding. Differential braking is one of the main control strategies of ESC, in which the braking force significantly depends on road friction conditions. If knowledge of road condition is available, the performance of ESC can be improved, as shown in [3–4]. In the cases of adaptive control and collision-avoidance systems, the real-time identification enables the braking distances to be adjusted in real time, thus improving the effectiveness and performance of these active control technologies [5].

Since many factors affect road friction coefficient, such as road materials, road conditions, tire types and pressure, vehicle velocity [6], the robust identification of maximum friction coefficient is always a difficult and challenging event in the automotive field.

This paper tries to develop a road surface identification approach based on "road characteristic value" to identify road surface conditions including road type, maximum road friction coefficient as well as optimal slip ratio. With the application of Burckhardt model, roads are divided into six types and the road characterization index named "road characteristic value" is proposed. The road characteristic value is defined as an integration of the road friction coefficient-slip ratio curve of the tire until a pre-defined slip ratio. By integration, more friction data are accumulated, and the contingency of the estimated outlier data can be eliminated, thus the main characterization of the road is extracted and the robustness of the identification is improved. Six kinds of road characteristic intervals based on road characteristic value threshold which represent typical road characterization are proposed, and the identified road can be obtained by determining which road's "road characteristic interval" the real-time road characteristic value falls in. In addition, this paper proposes a monitoring and identification algorithm for varying road conditions to detect and identify road changes during braking. Therefore, the integral road surface identification approach consists of the road characteristic value method and the variable road monitoring algorithm. The effectiveness of the proposed identification approach is verified through braking simulation tests under different road conditions based on a 14 DOF vehicle model. The rest of the paper is organized as follows: There is a literature review in Section 2. Section 3 introduces the establishment principle of 14 DOF vehicle model. In Section 4, the principle of the proposed road surface condition identification based on road characteristic value is illustrated. In Section 5,