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ORIGINAL ARTICLE

Stabilization of car-caravan combination using independent steer and drive/or brake forces distribution

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Abstract Once a combined vehicle becomes unstable, it is very difficult for a driver to stabilize it especially under severe driving conditions, such as turning with braking. This is mainly due to the effect of the towed vehicle on the towing vehicle through the hitch jackknifing. This effect makes the handling characteristics of a car-caravan combination different from those of a single vehicle. Therefore, this paper proposes a control design concept for an optimum distribution of longitudinal and lateral forces of the four tires of a towing vehicle. The mean objectives of the control system were to stabilize the motion of an articulated vehicle utilizing the tires entire ability in both longitudinal and lateral directions as well as to make the handling characteristics of an articulated vehicle similar to those of a single one. The sliding control law based on vehicle planar equations of motion is used to derive the control laws. The proposed control system is evaluated under severe driving conditions and compared with the results of integrated control systems. The robustness of the articulated vehicle motion with the proposed control against the coefficient of friction variation is discussed.

1. Introduction

Over the past three decades, various chassis control methods have been developed for improvement of the vehicle stability, handling characteristics and ride comfort. For example four-wheel steering system (4WS), direct yaw moment (DYC), anti-lock braking system (ABS), active front steering system (AFS), and active suspension have been developed and implemented on some passenger cars in the market. More recently, significant researches have been reported on integration of two or more controllers. Direct yaw moment and active steering control have been frequently employed in order to influence vehicle handling characteristics. Direct yaw moment control system relies on the remaining margin of tire longitudinal force. On the other hand, active steering system relies on remaining margin of tire lateral force. In active steering control technique an appropriate wheel sideslip angle is assigned to

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Nomenclature

a_x	longitudinal acceleration
a_x^*	traction/braking command from the driver
a_y	lateral acceleration
C_i	weighting coefficient
I_z	yaw moment of inertia
K_i	cornering stiffness of tire number i
K_f	cornering stiffness of front tire
K_r	cornering stiffness of rear tire
l	wheel base
$l_{f,r}$	distance between mass center and axle
L_x	hitch point longitudinal force
L_y	hitch point lateral force
M	total yaw moment
M_z	direct yaw moment control
m	vehicle mass
n	gear ratio
r	yaw rate
s	Laplace transform
t	vehicle tread
V	vehicle forward speed
X	total longitudinal force
X_i	required longitudinal force at tire number i
Y	total lateral force
$Y_{f,r}$	required lateral force at front/rear axle
Y_i	required lateral force at tire number i
$Z_{f,r}$	estimated vertical load
Z_i	estimated vertical load of tire number i
β	vehicle slip angle
β_e	estimated slip angle
δ	steering wheel angle
δ_w	wheel steering angle
$\delta_{f,r}$	active wheel steering angle
δ_i	active steering angle of tire number i
μ	friction coefficient

Subscripts

f	front
r	rear

wheel to develop the needed lateral force to follow the control law. Nowadays, x-by-wire technology in the automotive industry replaces the traditional mechanical and hydraulic control systems with electronic control systems using electromechanical actuators and human–machine interfaces such as pedal and steering feel emulators. Hence, the traditional components such as the steering column, intermediate shafts, pumps, hoses, fluids, belts, coolers and brake boosters and master cylinders are eliminated from the vehicle. Therefore, many active steering control and traction/braking control studies have emerged based on the new subject of x-by-wire system.

The author [1] analyzed the effect of optimum distribution of tire lateral and longitudinal forces on small passenger car performance. The results were compared to those obtained in the case without control and the case with combined control type direct yaw moment and rear and front active steering. Followed to this theoretical study, the author [2] has conducted experimental validation of the effect of the proposed system on the performance of small passenger car using driving simulator. Both theoretical and experimental results show that both controllers can be used effectively in situations close to the limit. However, in more severe driving situations, the combined control type direct yaw moment and rear and front active steering failed to achieve the desired aim while the optimum tire force distribution control successively achieved the desired responses. At the mean time, the author [3], investigated the effectiveness of weighting coefficients adaptation in the proposed simultaneous optimum distribution of tire lateral and longitudinal forces. Three different cases of weighting coefficients adaptation were considered. The computational results of this study showed that weighting coefficients adaptation can be used as design parameters for the designer to compromise between vehicle stability and responsiveness.

Most of these systems are available for single passenger cars, but not for heavier or complex vehicles, such as an articulated heavy-duty vehicle, or lighter vehicle configuration (e.g. car-caravan combination). However, when driving a multi-unit vehicle, the driver does not have enough information on the behavior of the rear unit(s), thus his/her action (steering, braking, acceleration) mainly depends on the actual state of the towing vehicle.

From the forgoing, the stability problems of light and heavy articulated vehicles are in the center of interest of the vehicle dynamicists. In [4,5] the system was designed to produce a stability torque acting on one unit of the vehicle configuration. In [6] a new concept called Active Unilateral Brake Control (AUBC) is applied for a car-caravan combination. The AUBC is applied for the towed vehicle part showing considerable improvement in the lateral stability. The effect of active rear wheel steering on the articulated vehicle stability is investigated in [5] while the effect of the all-wheel steering is investigated in [7]. It was concluded that these system can improve the vehicle stability. The author [8] examined the effect of direct yaw moment control system on the handling characteristics of a car-caravan combination. The yaw rate response of the two-degree of freedom vehicle motion (bicycle model) is chosen as a model response for the model following control. A computer simulation of a closed loop driver-vehicle system subjected to evasive lane change with braking was carried out in order to prove the effect of the control. It is proved that the effect of DYC is reasonable to prevent the combined vehicle from falling into unstable motion due to nonlinear tire characteristics as well as the combination of the car and the caravan. The work done in [8] has been extended to examine different models following types of yaw moment control strategy for improving handling safety of a car-caravan combination [9]. In these systems direct yaw moment control is generated by intentional distribution of tire longitudinal forces, where axle wheels bear the same amount of traction/braking force. The results show that the influence of the