

Effect of Steering Assistance Control by External Information Feedback Control and Chassis Control

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ABSTRACT

In this study, we report on the development of a steering assistance control system that feeds back information on the outside environment collected by laser sensors to the vehicle driver. The system consists of an emergency avoidance assistance control program that performs obstacle detection and avoidance, as well as a cornering assistance control program that operates by detecting the white lines painted on roadways. Driving simulator experiments were conducted in order to confirm the effectiveness of these functions, as well as to improve understanding of the synergistic effects of the steering assistance and chassis control functions: camber angle control and derivative steering assistance (DSA) control. In our emergency avoidance experiments, which were assisted by the obstacle detection function, the automatic override function successfully intervened to prevent accidents in situations where it determined that manual steering by the driver would be too late to avoid the detected obstacle. In our experiments involving cornering assistance by white line detection, smoother steering around curves was facilitated by the system's ability to set up an optimal approach earlier than could be expected by the curve recognition processes used by human drivers. In addition, vehicle stability at the approach and exit of a curve was enhanced by our steering system, which helps stabilize driving in critical cornering areas by effective use of camber angle control. Taken together, these steering assistance controls not only improve safety but also enhance the vehicle speed range because steering delays are minimized by the phase advances to actual steering behavior provided by the DSA control. It is expected that these systems have the potential to provide significant improvements in automotive safety.

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INTRODUCTION

In recent years, external recognition sensors installed to enhance safety have been widely applied to automobiles, and it is now possible to reduce traffic accidents by incorporating controls activated by feeding back sensor information unobtrusively during manual driving operations. Thus, it is clear we are gradually approaching the driverless automobile society currently under widespread discussion.

However, the joy of driving and the genuine thrill of owning a car might fade away once driverless automobiles become commonplace. Additionally, determining responsibility in the event of an accident has become a major issue. Therefore, in this study, we report on the development of a steering assistance system that can reduce human errors during collision avoidance and cornering operations by providing the driver with information obtained via external recognition sensors.

It is expected that during manual vehicle operations, such steering assistance systems would provide the driver with external world recognition sensor information on obstacles and curves faster than could be provided by humans senses, thereby giving him or her some

leeway to handle countermeasure operations. The purpose of this study is to confirm of superiority of a fusion of manual operation and assistance control.

Furthermore, powered motorization and automatic control of various automotive features is proceeding at an accelerating rate. Once complete motorization is achieved, vehicle motion control technology can be expected to evolve in wholly new ways. For example, it is now possible to control the tire camber angles by using electromagnetic actuators. Kobayashi et al.[1] reported that as the lateral force characteristic with respect to the camber angle increases, the maximum value of the lateral force can be achieved by inclining the tire camber angle in the negative direction at the critical cornering area of the larger tire slip angle. Thus, by maintaining a large camber angle in critical cornering areas, performance and safety are improved.

Most electric vehicle (EV) steering systems are "steer-by-wire", which means they are motor-based systems that operate on electric signals instead of mechanical couplings. Research into such steering systems, which included formulation of the derivative term, was pioneered by Hirao,[2-3] who also reported that yaw response rates and lateral acceleration in a normal driving area could be increased by the use of such systems.

On the other hand, in a study by Nozaki[4] that examined driver models at the time of drift area counter-steering, it was revealed that the drift cornering counter-steering delay could be improved by derivative steering assistance (DSA) control. Furthermore, they concluded that DSA control could be performed unobtrusively so as to cause no discomfort to the driver.

In the present study, the authors also explore a steering assistance control system based on external information feedback that is designed to expand safe driving limits by combining camber angle and DSA control.

EXPERIMENTAL APPARATUS

Driving Simulator to Simulate Drift Cornering

In this study, experiments were conducted using a driving simulator coupled with a motion device that is capable of replicating extensive yawing behavior and lateral acceleration through triaxial (yaw, roll, and lateral translational) control, thereby allowing dynamic behavior such as spin or drift in critical cornering areas. The driving simulator consists of a personal computer (PC) for control, a motion device, and control panels. Triaxial control is performed based on the yaw rates and lateral acceleration generated via the CarSim full-vehicle driving simulator developed by the Mechanical Simulation Corporation (MSC) of the USA.

The driving simulator configuration is shown in Figure 1, while the motion device dimensions and performance are shown in Table 1. Black curtains were drawn around the test subjects to enhance the sensation of actually driving, and test subjects operated the simulated vehicle based on moving images of actual driving situations projected on the PC monitor.

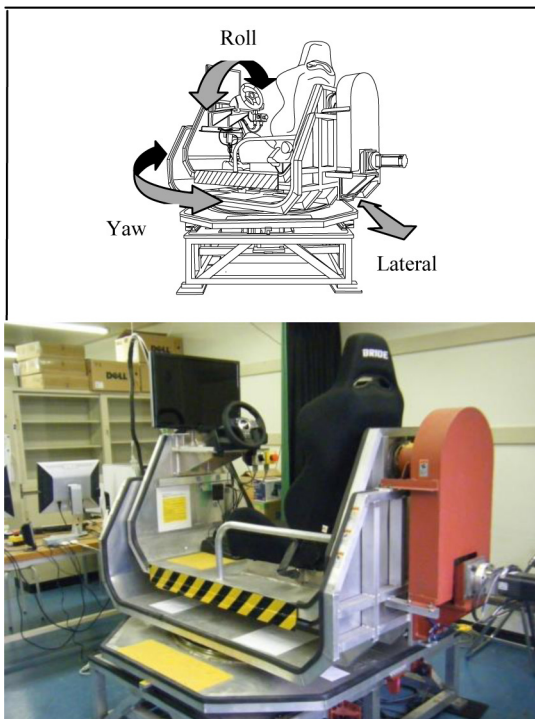


Figure 1. Driving simulator

Table 1. Driving simulator parameters and performance

Item	Performance
Actuator	AC servo motor
Control method	Three-axis control method for roll, yaw, and lateral movements (feedback control by potentiometer)
Main specifications	Shake & rotation frequency: 0–3 Hz <u>Roll motion</u> Max. angle: ± 20 deg Max. angular velocity: ± 50 deg/sec <u>Yaw motion</u> Max. angle: ± 90 deg Max. angular velocity: ± 40 deg/sec <u>Lateral movement</u> Max. displacement: ± 200 mm Max. velocity: ± 240 mm/sec Lateral acceleration: ± 0.7 G
Size of device	Width: 1525 mm, length: 2037 mm, height: 1800 mm
Weight of device	400 kg
Power supply	Single-phase AC 200 V and single-phase AC 100 V

Vehicle Model

Table 2 lists the main vehicle components and their degrees of freedom, while Table 3 shows the vehicle model parameters used in our experiments. The CarSim vehicle model considered herein has a front engine mount and rear drive (FR) layout that easily enters the drift state. For tire cornering force characteristics, we used the general tire characteristics shown in Figure 2. The maximum cornering force occurs at a slip angle of about 10° , and the acceleration and deceleration characteristics are as shown in Figure 3.

When added simultaneously, the slip angle and ratio are calculated using the friction circle concept based on CarSim's combined characteristics calculations. This concept produces simulated driving behaviors that match actual vehicle conditions when limitations are exceeded. Thus, when accelerating during the critical cornering limits, the rear wheels' maximum lateral force decreases as the rear-wheel drive force increases and the vehicle, which is now unable to withstand the centrifugal force, begins to spin out of control.

Table 2. Vehicle model components and degrees of freedom

Bodies	
Sprung mass body	1
Unsprung mass bodies (wheel carriers)	4
Rotating wheels	4
Engine crankshaft	1
Total	10
Degrees of freedom	
Sprung body translation	3
Sprung body rotation (yaw, pitch, roll)	3
Suspension stroke	4
Wheel spin	4
Powertrain (engine crankshaft)	1
Tire delayed slip (lateral, longitudinal)	8
Brake fluid pressure	
Total	27



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However, skillful control of the direction of travel of the front part of the vehicle body through counter-steering can put the vehicle into a drift-cornering maneuver. The final behavior experiment in this study demonstrates a rear-wheel skid. In this paper, the grip limit is defined as the point where the rear wheels generate the maximum cornering force.

Table 3. Calculation parameters

Width of vehicle (mm)	1795
Wheelbase (mm)	2780
Distance from center of front axle to center of gravity (mm)	1110
Height from ground to center of gravity (mm)	520
Vehicle mass (kg)	1370
Roll moment of inertia ($\text{kg} \cdot \text{m}^2$)	671.3
Pitch moment of inertia ($\text{kg} \cdot \text{m}^2$)	1972.8
Yaw moment of inertia ($\text{kg} \cdot \text{m}^2$)	2315.3

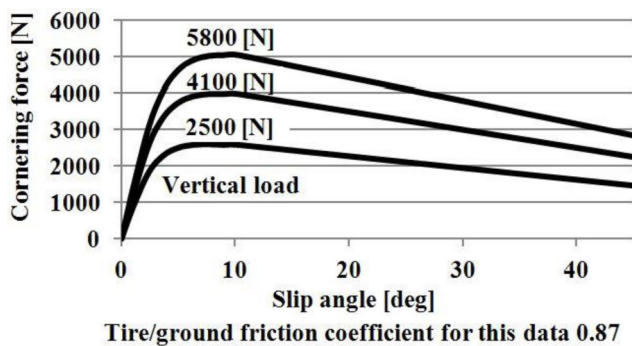


Figure 2. Tire lateral force characteristics

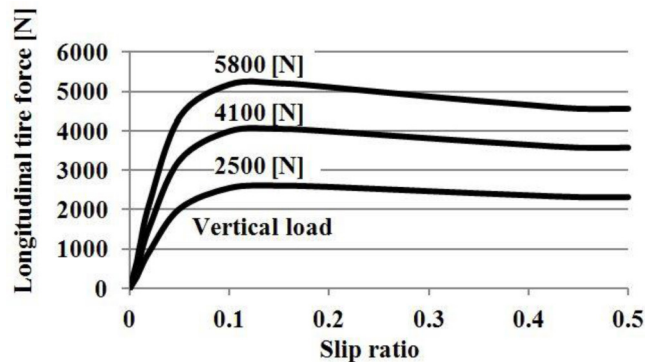


Figure 3. Longitudinal tire force characteristics

OUTLINE OF EACH CONTROL

Emergency Avoidance Assistance Control by Obstacle Detection

When an obstacle is detected by the sensors, the distance between the vehicle and the obstacle, L , and the angle of the obstacle, θ , is as shown in Figure 4. The control provides assistance by feeding back the distance and angle of the detected obstacle. Active assistance is

provided when the specified distance to the obstacle is less than the distance L . Left and right discrimination of the obstacle is carried out at an angle of θ . A block diagram overview of the process is shown in Figure 5. In this figure, steering assistance to the right is performed when there is an obstacle to the left, and steering assistance to the left is performed when there is an obstacle to the right. The proportion of manual steering and assisted steering was set at seven to three, which was selected in order to reduce the sense of discomfort imparted on the driver by steering assistance.

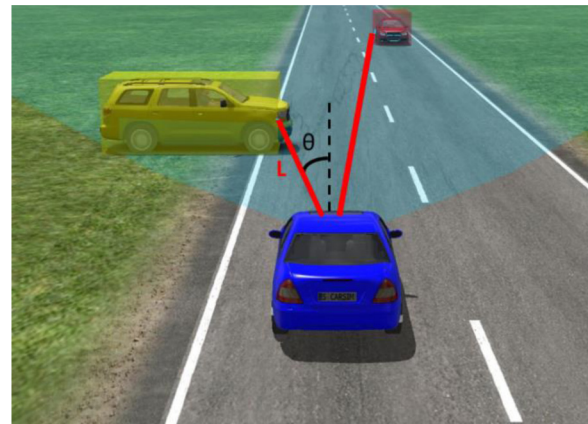


Figure 4. Sensor information

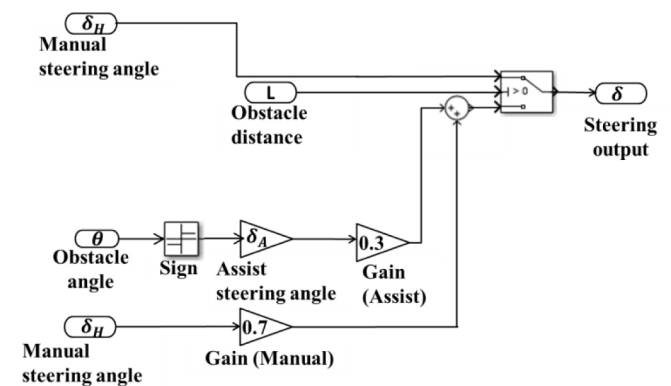


Figure 5. Block diagram of emergency assistance control by obstacle detection

Cornering Assistance Control by White Line Detection

When a white line is detected by the sensor, the angle between the white line and the vehicle was set to "+ θ " or "- θ ", as shown in Figure 6. The control provides assistance by feeding back the distance and angle of the white line, as shown the block diagram in Figure 7. Steering assistance conditions at the time of a right turn are met when the angle - θ of the sensors observing the white line on the left is greater than the straight driving value. Conditions of the steering assistance at the time of a left turn are met when the angle + θ of sensors observing the white line on the right is larger than the straight driving value. The ratio between manual and assisted steering was set to half the steering input value.