G-Vectoring, New Vehicle Dynamics Control Technology for Safe Driving

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OVERVIEW: Hitachi together with the Kanagawa Institute of Technology has developed a world-first technology for vehicle dynamics control that achieves smooth and stable cornering by automatically controlling longitudinal acceleration and deceleration based on how the driver turns the steering wheel as the vehicle travels around a corner. A strong correlation between longitudinal acceleration and lateral jerk can be found in the smooth driving of expert drivers, and this has been formalized in the equation (acceleration command value) = (lateral jerk) × (vehicle-specific gain) and given the name "G-Vectoring Control." G-Vectoring Control achieves safe and comfortable driving and is good for the environment because it minimizes energy loss and tire wear. It does this by rotating the combined vehicle acceleration vector (G) seamlessly about the center of the vehicle (vectoring), where this acceleration vector (G) is made up of components longitudinal and lateral to the vehicle. Hitachi is extending the use of this technology by applying it in various different systems where it is used as the underlying technology for vehicle dynamics control.

INTRODUCTION

A smooth driving style that reduces the unnecessary consumption of gasoline and emission of exhaust gases by avoiding rapid acceleration and sudden braking has been recommended in recent years as a response to the growing severity of global environmental problems. Manufacturers of the latest environmental vehicles are also taking the initiative

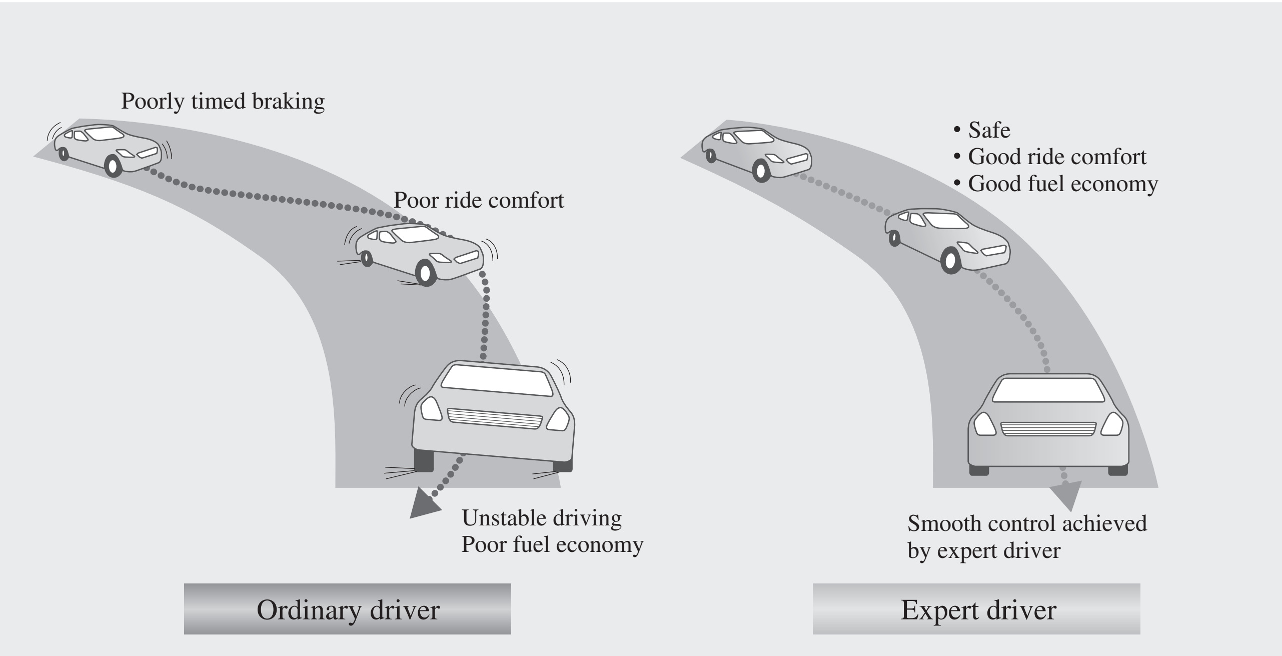

Fig. 1—Comparison of Ordinary and Expert Drivers.
The driving of an expert driver can be used as a measure of driving technique optimized for safety, ride comfort, tire wear, fuel economy, and other factors.

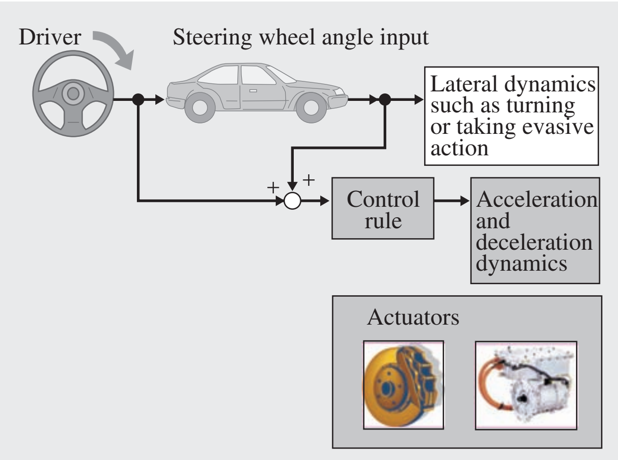

Fig. 2—Overview of Automatic Acceleration and Deceleration System that Operates in Concert with Steering Wheel.
The system automatically accelerates or decelerates in coordination with the driver's operation of the steering wheel. Smooth and stable cornering can be achieved by identifying a control rule that matches the driving of an expert driver. If the steering wheel were also under automatic control, the result would constitute an automatic driving system.

by installing interfaces such as eco-monitors that assist the driver to drive in an economical manner[1].

There is also a need to coordinate the operation of the steering wheel, accelerator, and brake in an appropriate way during cornering. This is an area where there is a clear difference in skills between expert and inexperienced drivers. Poor timing of accelerator or brake operation not only risks sudden braking mid-corner but may also require the vehicle to accelerate again to avoid being rear-ended by the following vehicle, for example. In addition to giving passengers an uncomfortable ride, this is something that needs to be improved for reasons of driving safety, fuel consumption, and tire wear (see Fig. 1).

It is for these reasons that Hitachi has been working with the Kanagawa Institute of Technology to develop the underlying technology for a driving assist system capable of smooth cornering. Specifically, the system accelerates or decelerates the vehicle in a way that feels natural based on how the driver is turning the steering wheel (see Fig. 2).

A particular focus is on how expert drivers coordinate operation of the steering wheel and brake. A system like that described above can be achieved by identifying and then reproducing the rules behind this coordinated control.

This article describes the driving analysis and control rule identification undertaken to implement the G-Vectoring, new vehicle dynamics control

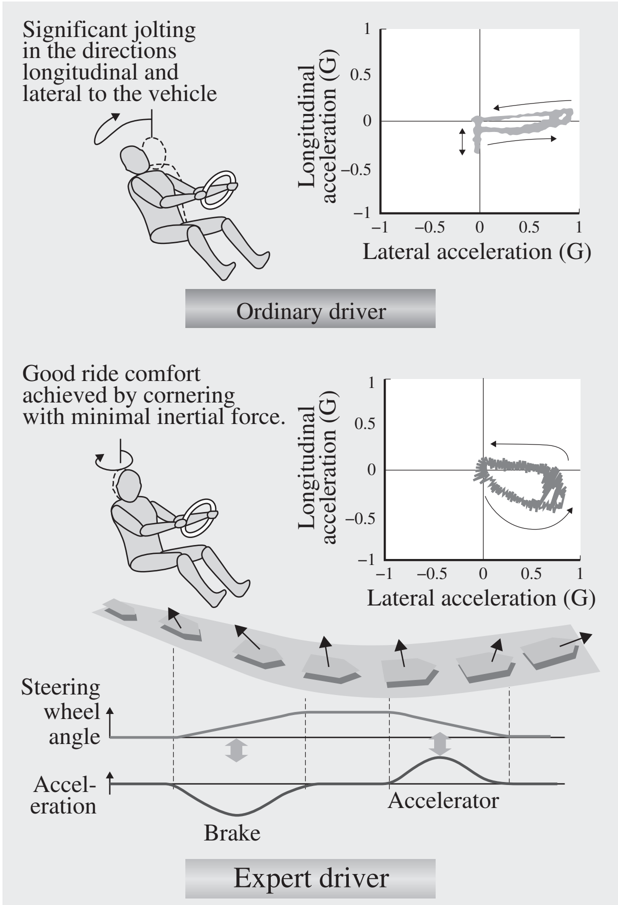

Fig. 3—Comparison of Ordinary and Expert Drivers.
The"g-g" diagrams plot lateral acceleration on the horizontal axis and longitudinal acceleration on the vertical axis, and show the extent to which these are coordinated.

technology for safe driving, and the results of trialing the system.

ANALYSIS OF EXPERT DRIVING

An analysis was conducted of both ordinary drivers and expert drivers who had received training to become test drivers for car manufacturers. The driving of the two groups, in terms of how they turned the steering wheel and accelerated or decelerated (used the accelerator or brake) as they drove around a curve, was compared by plotting the vehicle's acceleration on a "g-g" diagram[2] where lateral acceleration is plotted on the horizontal axis and longitudinal acceleration on the vertical axis (see Fig. 3).

Ordinary drivers tend to complete braking before entering the corner and then use the steering wheel only to navigate around the corner. If the driver misjudges the amount of deceleration, which is essentially guesswork, the result is a further speed adjustment involving wasted or abrupt acceleration

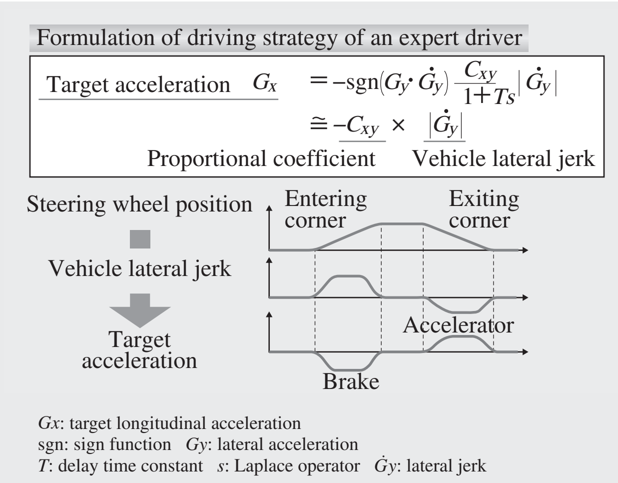

Fig. 4—Acceleration/Deceleration Control Rule for Lateral Dynamics Coordination.
This simple control rule essentially consists of applying a gain to the vehicle's lateral jerk to obtain the target acceleration or deceleration.

or deceleration.

For an ordinary driver, lateral acceleration undergoes a sudden step-change as the vehicle enters a corner and then abruptly diminishes again as the vehicle exits the corner. This style of driving causes the passengers to be jolted in the directions longitudinal and lateral to the vehicle.

An expert driver on the other hand, adjusts the level of acceleration or deceleration in harmony with their operation of the steering wheel, with the result that the longitudinal and lateral accelerations are coupled and the combined acceleration vector varies smoothly. With this style of driving, the absolute value of the inertial force to which the vehicle and passengers are subject follows a smooth and seamless curve without any sudden changes, reducing any jerkiness and improving ride comfort.

Another feature of expert drivers is that they decelerate precisely for the transition from driving straight to cornering. This deceleration causes the vehicle to lean forward and increases the vertical load on the front wheels. This also causes the front wheel tires to generate more cornering force[3]. Because this makes the steering more effective and eliminates the need to turn the steering wheel as far, it minimizes tire wear and reduces the energy loss caused by driving drag resistance.

In these ways, the driving of an expert driver saves energy and improves safety by improving handling and ride comfort.

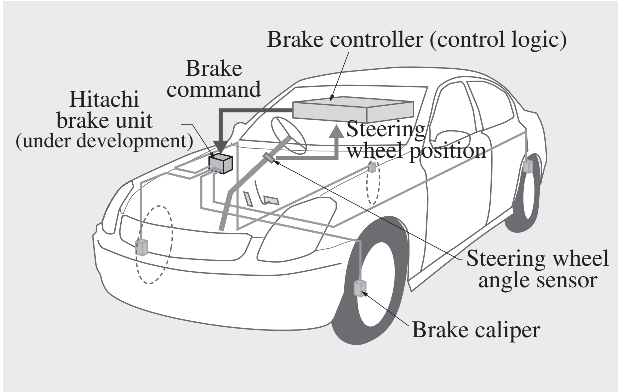

Fig. 5—Test Vehicle.
A Hitachi brake unit was installed to a standard commercially available vehicle. The system was capable of decelerating automatically based on the steering wheel angle information.

IDENTIFICATION OF CONTROL RULE

This smooth and precise cornering ability of expert drivers was investigated in detail using measurements taken from actual driving tests. The results indicated that the coordinated driving of an expert driver could be reproduced by controlling the longitudinal acceleration based on the lateral jerk (rate of change of acceleration with time) to which the vehicle is subject when the steering wheel is turned[4], [5].

Like an acceleration, jerk is a physical quantity that people can experience directly (in contrast to speed which we can only infer from visual information)[6]. Hitachi worked on jerk sensing and on vehicle dynamics control that used jerk sensing in the early 1990s[7] and now, nearly 20 years later, has identified an engineering application for jerk-based technology (see Fig. 4).

This control application works by ensuring that the combined acceleration vector (G) (the sum of the longitudinal and lateral acceleration components) rotates in a seamless way (vectoring). This control strategy is called G-Vectoring Control.

VEHICLE TEST RESULTS

Test Vehicle

A Hitachi brake unit was installed to a standard commercially available vehicle and G-Vectoring Control was tested based on use of the above control logic (see Fig. 5)[8].

Although the controller calculation generated both braking and acceleration instructions, the current trial focused on braking only and control of acceleration was left to the driver.

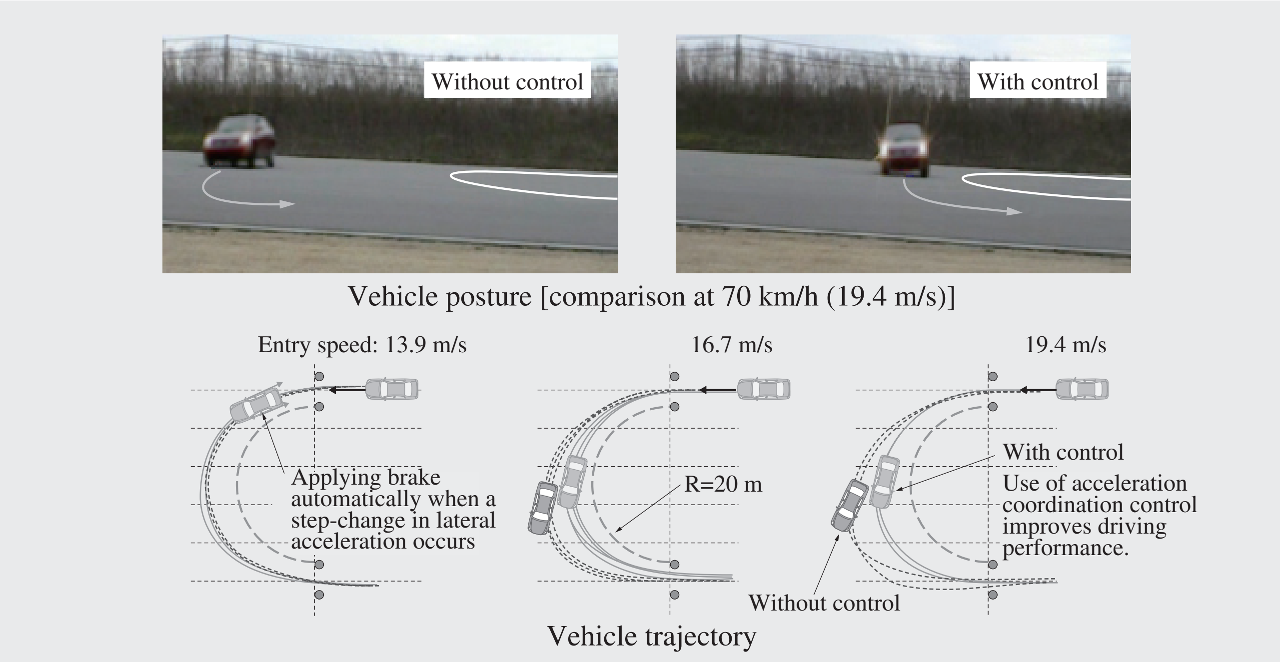

Fig. 6—Comparison of Vehicle Trace Performance.
The entry speed to the 20 m radius corner was stepped up gradually. Without the control system, it became more difficult to stay on the course as the speed increased.

The lateral jerk is obtained from the time-derivative of the acceleration which is in turn calculated from the steering wheel angle using the vehicle lateral dynamics model(3). Sensors for measuring steering wheel position have become a standard feature in recent years. Accordingly, a compact system could be implemented that did not require the installation of any additional sensors.

Driving tests were conducted to determine whether the numerous advantages provided by an expert driver described earlier could be reproduced on the test vehicle by using G-Vectoring Control.

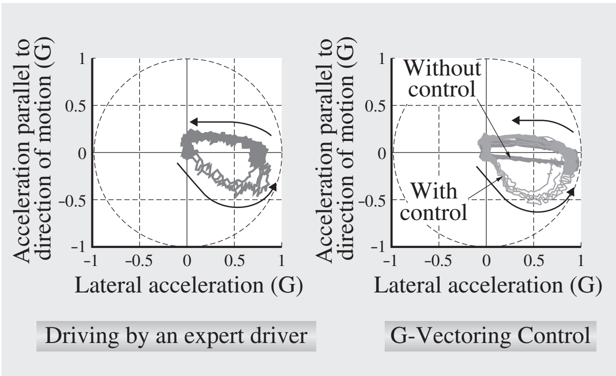

Fig. 7—Change in Acceleration during Driving.
G-Vectoring Control achieves seamless control of the combined acceleration in a similar way to an expert driver.

Corner Entry Characteristics

Fig. 6 shows the vehicle posture and trajectory as it travels around a corner with a 20-m radius at the designated speeds of 50 km/h, 60 km/h, and 70 km/h (13.9 m/s, 16.7 m/s, and 19.4 m/s). The figure shows a comparison of the trajectories with (solid line) and without (dotted line) control.

Although there is little difference between the trajectories at 50 km/h, the difference between the trajectories with and without control is clear at 60 km/h and even larger at 70 km/h.

The control can be expected to improve steering, prevent the driving line from swinging wide, reduce unnecessary acceleration, and improve safety and fuel economy.

Ride Comfort Improvement

A comparison was made of the changes in acceleration made by an expert driver and by G-Vectoring Control while traveling around a 20-m radius corner entered at a speed of 60 km/h (see Fig. 7).

The results show that control achieves a similar acceleration plot to that of the expert driver, confirming that head movement is minimal and ride comfort is improved.

CONCLUSIONS

This article has described the driving analysis and control rule identification undertaken to implement the G-Vectoring vehicle dynamics control technology for safe driving, and the results of trialing the system.

Although the G-Vectoring Control system described in this article was applied to automatic braking only, it is anticipated that application to both acceleration and braking would allow the system to be used as a general-purpose technology for mechanisms such as energy regeneration using an electric motor.

Also, the current system does not make use of forward-looking or road and traffic information such as that obtained from cameras, radar, or GPS (global positioning system). Rather it has simply been implemented and tested as an underlying technology for improving the driving performance of the vehicle.

In addition to this technology, Hitachi intends to continue proposing total solutions and building attractive systems that utilize information from the external environment.

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