Driver Model Based Handling Quality Evaluation and Effects of Vehicle Body Motion on Handling Quality Improvement with G-Vectoring Control (GVC)

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Introduction and Outline of The Lecture

1. G-Vectoring Control (GVC) is a vehicle motion control in which the longitudinal motion is controlled depending on the lateral motion.

2. Mazda has introduced passenger cars with GVC into real market and significant effects of GVC on improving vehicle handling performance not necessarily during severe motion but in a normal vehicle motion by ordinary drivers have been confirmed.

3. A specific feature of the effects of GVC is that though the control gain of the longitudinal motion is very small, a big performance improvement in lateral motion of the driver-vehicle system is available. Therefore, fundamental effects of GVC on handling performance especially on a subtle influence on driver’s handling quality evaluation should be investigated satisfactorily.

4. Since the subjective handling quality evaluation by the ordinary drivers is not always consistent and reliable, a driver model based evaluation method, which is more objective and quantitative evaluation method, has been introduced.

5. The fundamental effect of GVC itself on the handling quality is experimentally investigated using the experimental full drive-by-wire electric powered vehicle by the model based evaluation method.

6. As GVC controls the longitudinal acceleration depending on lateral acceleration, it directly affects the body motion and it seems that a vehicle body motion has a significant effect on the vehicle handling quality evaluation with GVC. Therefore, in order to investigate the effects of GVC on handling quality more in detail, the experimental analysis how the vehicle body motion especially the pitch motion affects the effects of GVC on the handling quality evaluation is investigated.
Overview of G-Vectoring Control (GVC)
Control algorithm of GVC

\[ G_{xc} = -\text{sgn}(G_y \cdot \dot{G}_y) \frac{C_{xy}}{1 + Ts} |\dot{G}_y| \]

Longitudinal motion is controlled in coordination with the lateral motion.

\[ G_{xc} \]: Longitudinal acceleration command, \( C_{xy} \): Control gain, \( G_y \): Lateral acceleration
Movement of ball-in-bowl on board with GVC draws G-G diagram during entering into and out of the curve.

The name “G-Vectoring Control” comes from this change of the direction of resultant acceleration.
Mazda has introduced passenger cars with GVC by engine torque control into real market.

Source: www.mazda.co.jp/dynamics/skyactive/interview/gvc/01/
Measured data during Journalists test drive events

EVALUATION BY JOURNALISTS: STRAIGHT AHEAD DRIVING AT 80KPH

- Driver continuously modulates steering wheel angle to keep straight ahead.

![Graphs showing SWA and SWV with and without GVC for Driver A and Driver B.](image)
Measured data during Journalists test drive events

EVALUATION BY JOURNALISTS: STRAIGHT AHEAD DRIVING AT 80KPH

- Driver continuously modulates steering wheel angle to keep straight ahead.

[Graphs showing SWA and SWV over time for Drivers C and D with and without GVC]
EVALUATION BY JOURNALISTS : STRAIGHT AHEAD DRIVING AT 80KPH

- Steering correction (standard deviation) reduces with most of the drivers due to GVC.
- Subjective comments by the drivers are:
  - “Increased controllability in small steering operation”
  - “More planted feel at straight ahead driving“
  - “Look-ahead distance has naturally increased“
- GVC improves handling quality by responding to subtle steering operation.
Driver Model Based Handling Quality Evaluation Method

Subjective evaluation

Objective and quantitative evaluation
Driver model for lane change

\[ y_0 + \frac{h(1 + \tau_h s)e^{-\tau_L s}}{1 + T_h s} \delta_h \rightarrow \theta \]

Driver

Vehicle

Objective path

\[ L \theta \]

\[ \delta \]

\[ \theta \]

\[ L \]

\[ y_0 \]

\[ y \]
Simplified driver model for sudden lane change on straight road with constant lane width

\[
\frac{\delta_h}{y_{L0} - (1 + \tau_h s)y} = \frac{h}{1 + \tau_L s}
\]

3 driver handling parameters to be identified
Driver parameter identification

Find $\tau_L$, $h$, $\tau_h$ to minimize the error here

Driver parameters

$\tau_L$ : Response delay time [s]

$\tau_h$ : Preview time [s]

$h$ : Control gain[-]

Measured time history of vehicle motion
Finding driver handling parameters

\[
\frac{\delta_h}{y_{L0} - (1 + \tau_h s)y} = \frac{h}{1 + \tau_L s}
\]

\[
(1 + \tau_L s)\delta_h = -h\{(1 + \tau_h s)y - y_{L0}\}
\]

Measured real steering angle  
Calculated steering angle by driver model using measured vehicle lateral position

\[
\varepsilon = (1 + \tau_L s)\delta_h + h\{(1 + \tau_h s)y - y_{L0}\}
\]

\[
J = \int \varepsilon^2 \, dt = \int_0^T \left[ \delta_h + \tau_L \frac{d\delta_h}{dt} + h(y - y_{L0}) + h\tau_h \frac{dy}{dt} \right]^2 \, dt
\]

Finding the driver steer parameters, \( h, \tau_h \) and \( \tau_L \), to minimize \( J \)

\[
\frac{\partial J}{\partial h} = 0, \quad \frac{\partial J}{\partial (h\tau_h)} = 0, \quad \frac{\partial J}{\partial \tau_L} = 0
\]
Relationships between handling quality and driver parameter

\[ y_{L0} \rightarrow Driver \rightarrow \frac{h}{1 + \tau_L s} \rightarrow Vehicle \rightarrow y \]

Steering angle \( \delta_h \)

Target lateral displacement

Deviation of course

Current lateral displacement

\[ \tau_L : \text{All the response delay of the driver during the lane change} \]

If \( \tau_L \) is large \( \rightarrow \) Slow, relaxed behavior \( \rightarrow \text{is enough to complete lane change with ease} \)

Driving with a margin, easier \( \rightarrow \) Higher handling quality evaluation

The handling quality evaluation is quantified objectively by the parameter value of \( \tau_L \).
Some Examples of Reflections of Vehicle Response Characteristics to Driver Parameter $\tau_L$ – Handling Quality Evaluation
Airplane short period mode of longitudinal response

\[ \frac{q(s)}{\delta(s)} = \frac{G}{1 + \frac{2\zeta s}{\omega_n} + \frac{s^2}{\omega_n^2}} \]

Pilot rating on the longitudinal response

Relation of vehicle response parameters, \( \omega_n \) and \( \zeta \), to handling quality evaluation
Road vehicle side-slip and yaw rate responses

\[
\frac{\beta(s)}{\delta(s)} = G_\delta^\beta(0) \frac{1 + T_\beta s}{1 + \frac{2\zeta}{\omega_n} s + \frac{s^2}{\omega_n^2}}
\]

\[
\frac{r(s)}{\delta(s)} = G_\delta^r(0) \frac{1 + T_r s}{1 + \frac{2\zeta}{\omega_n} s + \frac{s^2}{\omega_n^2}}
\]
Vehicle responses to front steer input are rewritten as:

$$\beta(s) = G_\delta^\beta (0) \frac{1+T_\beta s}{1+\frac{2\zeta}{\omega_n} s + \frac{s^2}{\omega_n^2}} \frac{\delta_f(s)}{\delta_h(s)} \delta_h(s)$$

$$r(s) = G_\delta^r (0) \frac{1+T_r s}{1+\frac{2\zeta}{\omega_n} s + \frac{s^2}{\omega_n^2}} \frac{\delta_f(s)}{\delta_h(s)} \delta_h(s)$$

If front wheel active steer is set as follows:

$$\frac{\delta_f(s)}{\delta_h(s)} = \frac{1+\frac{2\zeta}{\omega_n} s + \frac{s^2}{\omega_n^2}}{1+\frac{2\zeta^*}{\omega_n^*} s + \frac{s^2}{\omega_n^*^2}}$$

Variable response parameter vehicle in denominator, $\omega_n^*$ and $\zeta^*$ is available from just above front wheel active steer only as follows:

$$\frac{\beta(s)}{\delta_h(s)} = G_\delta^\beta (0) \frac{1+T_\beta s}{1+\frac{2\zeta^*}{\omega_n^*} s + \frac{s^2}{\omega_n^*^2}}$$

$$\frac{r(s)}{\delta(s)} = G_\delta^r (0) \frac{1+T_r s}{1+\frac{2\zeta^*}{\omega_n^*} s + \frac{s^2}{\omega_n^*^2}}$$
\[ \zeta^* = \zeta (1 + \alpha_1), \quad \omega_n^* = \omega_n (1 + \alpha_2) \quad \text{where} \quad |\alpha_1|, |\alpha_2| << 1.0 \]

If \( \zeta^* = \zeta (1 + \alpha_1), \quad \omega_n^* = \omega_n (1 + \alpha_2) \) where \( |\alpha_1|, |\alpha_2| << 1.0 \)

then

\[
\frac{\delta_f(s)}{\delta_h(s)} = \frac{1}{n} \frac{1 + \frac{2\zeta}{\omega_n} s + \frac{1}{\omega_n^2} s^2}{1 + \frac{2\zeta (1 + \alpha_1)}{\omega_n (1 + \alpha_2)} s + \frac{1}{\omega_n^2 (1 + \alpha_2)^2} s^2}
\]

\[
\approx \frac{1}{n} \frac{1 + \frac{2\zeta}{\omega_n} s + \frac{1}{\omega_n^2} s^2}{1 + \frac{2\zeta}{\omega_n} s + \frac{1}{\omega_n^2} s^2 + \frac{2\zeta}{\omega_n} (\alpha_1 - \alpha_2) s - \frac{2}{\omega_n^2} \alpha_2 s^2}
\]

\[
\approx \frac{1}{n} \left[ \frac{\frac{2\zeta}{\omega_n} (\alpha_1 - \alpha_2 - \frac{1}{\zeta\omega_n} \alpha_2 s) s}{1 + \frac{2\zeta}{\omega_n} s + \frac{1}{\omega_n^2} s^2} \right]
\]

Direct steer part by driver

Active steer part
Driving simulator with external motion control for variable response parameter vehicle

External motion Control System

\[
\frac{\delta}{\delta_h}(s) \approx \frac{1}{n} \left[ \frac{2\zeta}{\omega_n} \left( \alpha_1 - \alpha_2 - \frac{1}{\zeta \omega_n} \alpha_2 s \right) \frac{s}{1 + \frac{2\zeta}{\omega_n} s + \frac{1}{\omega_n^2} s^2} \right]
\]

variable stability vehicle
Frequency response of driving simulator with variable response parameter at $V=80\text{km/h}$
Lane change test

2.5m → 80[km/h]

3.0m

3.0m

45[m]
Calculated motion in driving simulator and measured motions of moving base
Identified driver parameter $\tau_L$ on $\omega_N$-$\zeta$ plane ($V=80\text{km/h}$, $L_C=45\text{m}$)
Averaged four driver parameters $\tau_L$ on $\omega_n$-$\zeta$ plane
($V=80\text{km/h}, \ L_C=45\text{m}$)
The Same Experiment Using Real Vehicle

Two active chassis controls for experimental vehicle (VSV)

- DYC (direct yaw-moment control) : $M$
- RWS (rear wheel active steer) : $\delta_r$

Linear-2degree-of-freedom-model with the two active chassis controls

$$
\begin{align*}
\{mVs + 2(K_f + K_r)\} \frac{\beta(s)}{\delta(s)} + \left\{mV + \frac{2}{V}(l_f K_f - l_r K_r)\right\} \frac{r(s)}{\delta(s)} &= 2K_f \frac{\delta(s)}{n \dot{\delta}(s)} + 2K_r \frac{\delta_r(s)}{\delta(s)} \\
2(l_f K_f - l_r K_r) \frac{\beta(s)}{\delta(s)} + \left\{Is + \frac{2(l_f^2 K_f + l_r^2 K_r)}{V}\right\} \frac{r(s)}{\delta(s)} &= 2l_f K_f \frac{\delta(s)}{n \dot{\delta}(s)} - 2l_r K_r \frac{\delta_r(s)}{\delta(s)} + M(s) \frac{\delta(s)}{\delta(s)}
\end{align*}
$$

Solving inverse equations by $M(s)/\delta(s)$ and $\delta_r(s)/\delta(s)$

Model responses

$$
\begin{align*}
\frac{M_z(s)}{\delta} &= -\frac{2lK_f}{n} + \left(ml_r Vs + 2lK_f\right) \frac{\beta_m(s)}{\delta(s)} + \left(Is + ml_r V + \frac{2l_f lK_f}{V}\right) \frac{r_m(s)}{\delta(s)} \\
\frac{\delta_r(s)}{\delta} &= -\frac{1}{n} \frac{K_f}{K_r} + \frac{mVs + 2(K_f + K_r)}{2K_r} \frac{\beta_m(s)}{\delta(s)} + \left(\frac{mV}{2K_r} + \frac{l_f K_f - l_r K_r}{K_r V}\right) \frac{r_m(s)}{\delta(s)}
\end{align*}
$$
Model response to steer input

\[
\frac{\beta_m(s)}{\delta(s)} = G_\delta^\beta(0) \frac{1 + T_\beta s}{1 + \frac{2\zeta}{\omega_n} s + \frac{1}{\omega_n^2} s^2}
\]

\[
\frac{r_m(s)}{\delta(s)} = G_\delta^r(0) \frac{1 + T_r s}{1 + \frac{2\zeta}{\omega_n} s + \frac{1}{\omega_n^2} s^2}
\]

\[
\omega_n = \alpha_N \frac{2l}{V} \sqrt{\frac{K_f K_r}{m I}} \sqrt{1 + AV^2}
\]

\[
\zeta = \alpha_D \frac{m(l_f^2 K_f + l_r^2 K_r) + I(K_f + K_r)}{2l \sqrt{m I K_f K_r (1 + AV^2)}}
\]

\[
T_r = \alpha_R \frac{ml_f V}{2l K_r}
\]

\[
A = -\frac{m}{2l^2} \frac{l_f K_f - l_r K_r}{K_f K_r}
\]

\[
T_\beta = \frac{IV}{2l l_r K_r} \frac{1}{1 - \frac{m}{2l} \frac{l_f}{l_r} V^2}
\]

\[
G_\delta^\beta(0) = \frac{1 - \frac{m}{2l} \frac{l_f}{l_r} V^2}{1 + AV^2} \frac{1}{l}
\]

\[
G_\delta^r(0) = \frac{1}{1 + AV^2} \frac{V}{l}
\]

Adjustment parameters \( \alpha_N, \alpha_D, \alpha_R \)
Experimental VSV with active chassis controls

Feed-forward type of model following control algorithm

\[
\frac{\beta_m(s)}{\delta(s)} = \frac{r_m(s)}{\delta(s)}, \quad M(s) = \frac{\delta_r(s)}{\delta(s)}
\]

\[
\delta_r = M(s) \delta(s)
\]

- Speed sensor
- Steering angle sensor
- GPS
- Acceleration sensor
- Yaw rate sensor
- Micro auto box
- Actuator for DYC
- Actuator for RWS
Frequency response of VSV at $V=80$km/h

- **Lateral acceleration**
  - Gain [l/s]
  - Phase [deg]
  - Gain [G/rad]
  - Phase [deg]

- **Yaw rate**
  - Gain [l/s]
  - Phase [deg]
  - Gain [G/rad]
  - Phase [deg]
Lane change test

- Distance: 2.5m
- Speed: 80km/h
- Lane separation: 3.0m
- Overall distance: 30m
$\omega_n$, $\zeta$ and driver handling parameter $\tau_L$

average value of each driver

average value of four drivers

Blue : Driver A  Red : Driver B  Green : Driver C  Gray : Driver D
Effects of steering torque characteristics on handling quality evaluation

Steering angle – torque characteristics

Case 1: $K_s=0, K_f=0, FW=0, c=0$
- Without torque

Case 2: $K_s=2, K_f=0, FW=0, c=0$
- Pure spring

Case 3: $K_s=2, K_f=0, FW=0, c=0.3$
- Pure spring + damping

Case 4: $K_s=0, K_f=10, FW=1, c=0$
- Spring-friction

Case 5: $K_s=2, K_f=10, FW=1, c=0$
- Pure spring + spring-friction

Case 6: $K_s=2, K_f=10, FW=1, c=0.3$
- Pure spring + spring-friction + damping
Effects of steering torque on handling quality

Driver
(steering wheel)

Steering reaction torque
Steering angle

Vehicle motion
Data logging

Calculation of vehicle motion

Steering angle

Steering torque generation system
(coneKt, TRW)

Steering angle

Steering torque model

Steering torque [Nm]
Steering angle [deg]

Steering angle command

Driving simulator

Motion & visual display
Lane change course

<table>
<thead>
<tr>
<th>Vehicle speed [km/h]</th>
<th>Lane change length : $L_c$ [m]</th>
<th>width [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>40</td>
<td>2.5</td>
</tr>
<tr>
<td>140</td>
<td>55</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
</tr>
</tbody>
</table>
100km/h, Lc=55m
140km/h, Lc=70m
Averaged increase rate of $\tau_L$ and driver's subjective rating.
The interesting point is that the steering torque has the indirect effects on the driver steering angle control parameters as if the vehicle response characteristics to steering angle input changes, even though there is no change in the vehicle response. Actually it is clear that the steering torque has nothing to do with the open-loop transfer function in the above control block diagram.
Now back to GVC

Investigation into Effects of GVC on Handling Quality Evaluation Using Full Drive-by-Wire Experimental EV
Experimental full drive-by-wire electric vehicle

Four wheels independent driving and braking

Table 1. Basic specification of the vehicle

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle mass</td>
<td>m 709 [Kg]</td>
</tr>
<tr>
<td>Yaw moment of Inertia</td>
<td>l_z 512 [kg·m²]</td>
</tr>
<tr>
<td>Wheel base</td>
<td>l 2.050 [m]</td>
</tr>
<tr>
<td>C.O.G. to front axis</td>
<td>l_f 1.012 [m]</td>
</tr>
<tr>
<td>C.O.G. to rear axis</td>
<td>l_r 1.038 [m]</td>
</tr>
<tr>
<td>Front tread</td>
<td>d_f 1.415 [m]</td>
</tr>
<tr>
<td>Rear tread</td>
<td>d_r 1.415 [m]</td>
</tr>
<tr>
<td>Height of C.O.G.</td>
<td>h_s 0.417 [m]</td>
</tr>
</tbody>
</table>

All wheel independent steering

Installation of steering system (No column)

Left and right Tie rods are not connected each other
Lane change course

Start of lane change section

Either right or left strobe light flashed

Course outline
- Running speed: 40[km/h]
- Lane change width: 2.5[m]
- Lane change margin: 18[m]

Driver changes the lane to randomly flashed direction
Experimental Condition

Lower arm angle 0 [deg] (Pitch-free)

- Without GVC
- With GVC

Repeated 15 times left and right

Evaluation for the “Driver model-based handling quality evaluation method”

Drivers for the test

<table>
<thead>
<tr>
<th>Participants</th>
<th>M/F</th>
<th>Age</th>
<th>Drive experience</th>
<th>Drive frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>M</td>
<td>22</td>
<td>4 years</td>
<td>Weekly</td>
</tr>
<tr>
<td>B1</td>
<td>M</td>
<td>21</td>
<td>2 years</td>
<td>Daily</td>
</tr>
<tr>
<td>C1</td>
<td>M</td>
<td>23</td>
<td>4 years</td>
<td>Daily</td>
</tr>
<tr>
<td>D1</td>
<td>M</td>
<td>23</td>
<td>4 years</td>
<td>Weekly</td>
</tr>
<tr>
<td>E1</td>
<td>M</td>
<td>21</td>
<td>3 years</td>
<td>Daily</td>
</tr>
</tbody>
</table>
Effects of GVC on vehicle motion

Reduced steering angle
Smooth yaw rate change

Typical GVC effects were found

Free to pitch
Effects of GVC on handling quality evaluation by $\tau_L$

Larger $\tau_L$ corresponds with higher handling quality

Driver model-based handling quality evaluation by $\tau_L$ is useful!
Supposed factors for good handling quality evaluation

The distinctive high quality evaluation of GVC is due to:

1. Smooth acceleration transition of $G_x$ and $G_y$ ("g-g diagram", 2D).
2. Body motion, roll motion accompanied by pitch motion (Diagonal roll).

Which is dominant? Which is essential for the better feeling?
Investigation how the vehicle pitch motion affects GVC improving the handling quality
All wheel independent steer

4 wheel in-wheel motors

Running direction

Upper arm

Lower arm

Suspension lower arm can be adjusted for the anti-dive/lift angle
How to change the body motion

Variable suspension geometry

Running direction

Upper arm

Lower arm

Front

Rear

Anti-dive force

\[-X_f \cdot \tan \theta_f\]

\[-X_f\]

\[\theta_f\]

Instantaneous rotational center

Anti-Lift force

\[-X_r \cdot \tan \theta_r\]

\[-X_r\]

\[\theta_r\]
Pitch motion restrain system

Pitch motion was restrained even if the vehicle decelerates by GVC

Pitch motion restrain moment caused by vertical force

Pitch moment caused by longitudinal force (nose-dive)

Anti-dive force

$-X_f \cdot \tan \theta_f$

$-X_f$

Front

$\theta_f$

Instantaneous rotational center

Anti-Lift force

$-X_r \cdot \tan \theta_r$

$-X_r$

Rear

$\theta_r$
## Setup of the experimental vehicle

<table>
<thead>
<tr>
<th>Suspension set up (Link alignment)</th>
<th>Case1</th>
<th>Case2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without GVC</td>
<td>With GVC</td>
<td>Without GVC</td>
</tr>
</tbody>
</table>

- **Pitch-free**
  - **Without GVC**
  - **With GVC**
  - **G-linkage**
    - No
    - Yes
  - **Diagonal roll (Nose-dive pitch motion)**
    - No
    - Yes

- **Pitch-restrained**
  - **Without GVC**
  - **With GVC**
  - **G-linkage**
    - No
    - Yes
  - **Diagonal roll (Nose-dive pitch motion)**
    - No
    - Yes
Influence of body pitch motion

Experimental Condition
Lower arm angle 0° & 30° (Pitch-free & pitch-restrained)
- Without GVC
- With GVC
Repeated 15 times left and right

Drivers for the test

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<tbody>
<tr>
<td>A2</td>
<td>M</td>
<td>27</td>
<td>9 years</td>
<td>Daily</td>
</tr>
<tr>
<td>B2</td>
<td>M</td>
<td>23</td>
<td>5 years</td>
<td>Weekly</td>
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Some of them are different members
Case 1: Pitch motion free

- **GVC on**
- **GVC off**

Steer action becomes slow with GVC

Nose down pitching by control

Both G-linkage and Nose-dive were realized
Case 2: Pitch motion restrain

- GVC on
- GVC off

Steering has not changed even with GVC on

Pitch motion does not change so much with GVC and without

Pitch motion caused by GVC was restrained
Case 1: Pitch motion free

Larger $\tau_L$ corresponds with higher handling quality

GVC is effective consistently on handling quality improvement for the vehicle with pitch motion free
Case 2: Pitch motion restrained

Larger $\tau_L$ corresponds with higher handling quality

Handling quality improvement are not consistent when the vehicle pitch motion restrained
The nose-dive of GVC is very small, but indispensable for the good handling quality!
Effect of the vehicle pitch motion itself without longitudinal acceleration control on improving the handling quality
Effect of the vehicle pitch motion itself without longitudinal acceleration control on improving the handling quality

<table>
<thead>
<tr>
<th>Experimental task</th>
<th>Suspension arm Front:0° Rear:20°</th>
<th>Suspension arm Front:0° Rear:20°</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Pitch motion</td>
<td>-</td>
<td>Nose dive</td>
<td>Nose up</td>
</tr>
<tr>
<td>Drive distribution</td>
<td>-</td>
<td>Front : Braking Rear : Traction</td>
<td>Front : Traction Rear : Braking</td>
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The longitudinal acceleration is not generated by the control but the vehicle body pitch motion is changed.

drivers

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<td>E</td>
<td>M</td>
<td>22</td>
<td>3 years</td>
<td>Daily</td>
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With nose-dive pitch motion

With nose-up pitch motion
Summary

1. A new vehicle motion control, GVC, is introduced.
2. Model based objective handling quality evaluation method is introduced and confirmed to be effective to evaluate such a subtle effect of GVC on handling quality for ordinary drivers.
3. The vehicle small pitch motion has a fundamentally significant influence on the result of the handling quality evaluation with GVC.
4. The yaw motion accompanied by the nose-dive pitch motion “diagonal-roll” during lane change makes the driver more perceptive to feel the responsive vehicle yaw motion.
5. Subtle effects of body motion on the driver’s handling quality evaluation seems very important to make ever-better cars – the vehicle fun to drive.
Thank you very much for your attentions