VEHICLE DYNAMICS EXPO 2012

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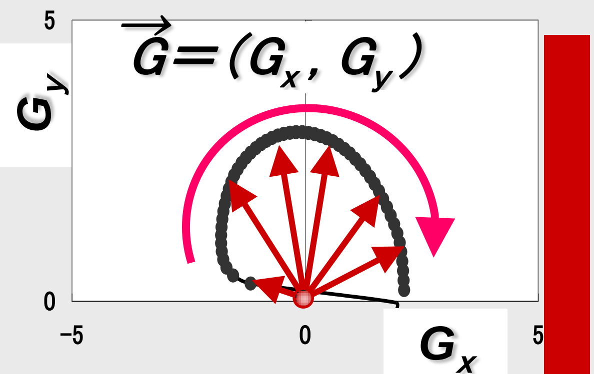
G-Vectoring

neue Kontrolltechnologie in der Fahrzeugdynamik fur sicheres und economical Fahren

Dr. -Ing. Makoto. Yamakado

Hitachi, Ltd. , Japan



Basic principle (Expert-driver based)

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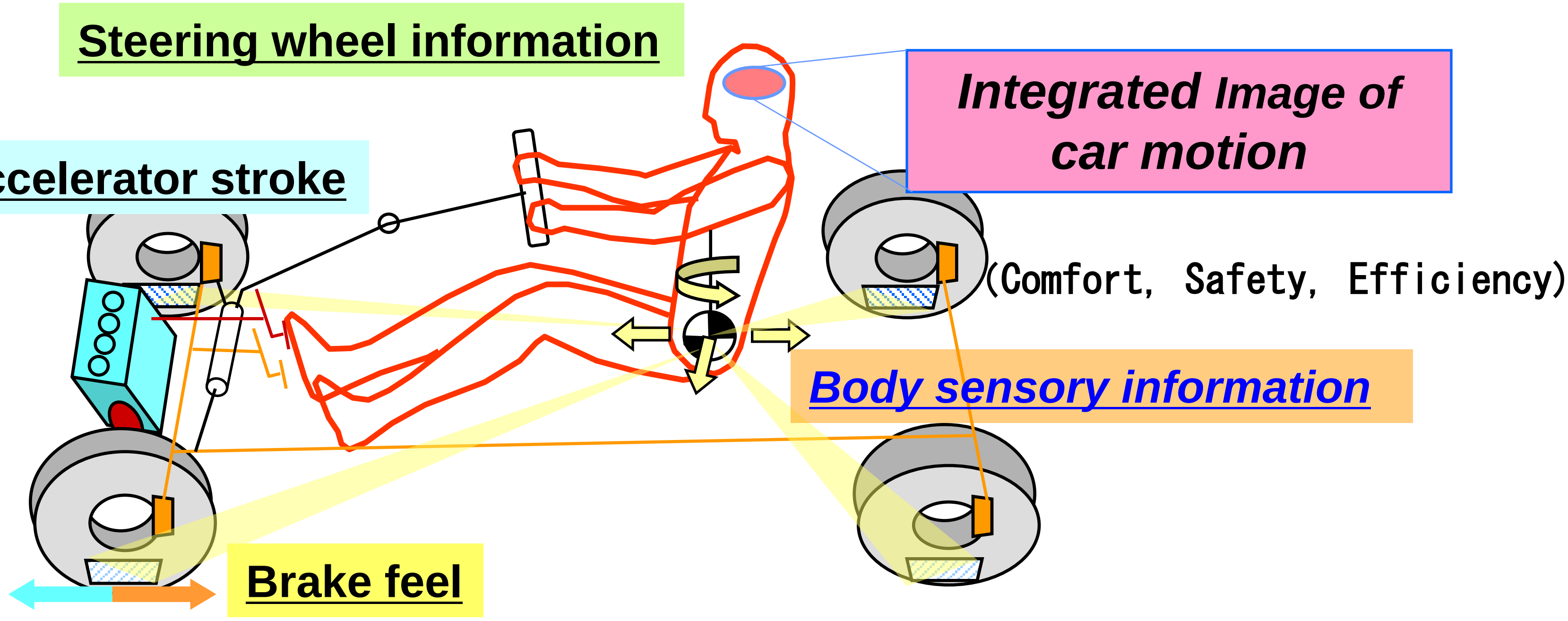

The driver drives car using various information, to reach an ideal integrated image of the car motion.

The driver is longitudinal and lateral
Combination motion controller
(Expert driver performs very well)

Technological use (Let's iwithate it!)

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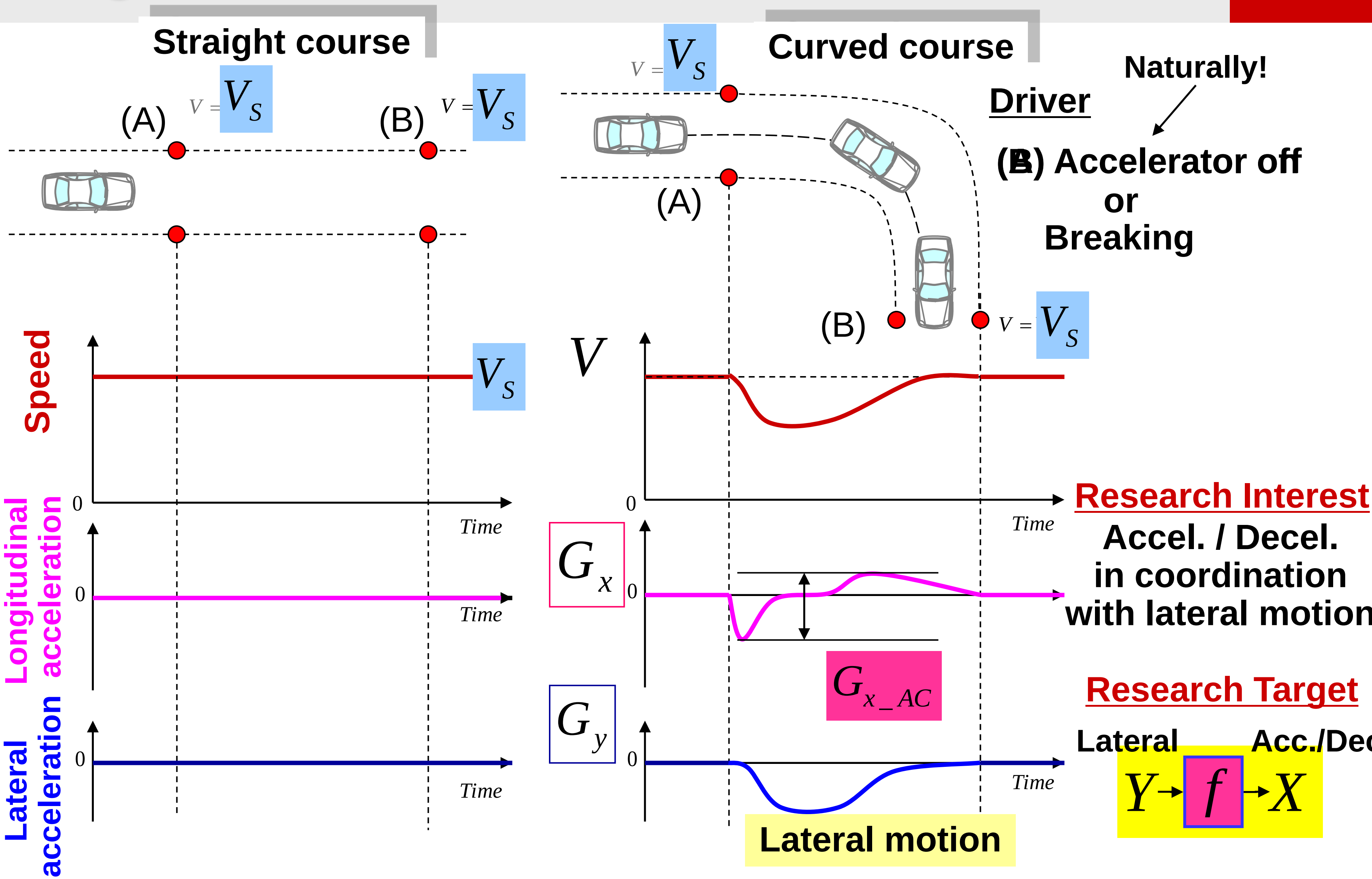
Longitudinal Control in coordination with lateral motion

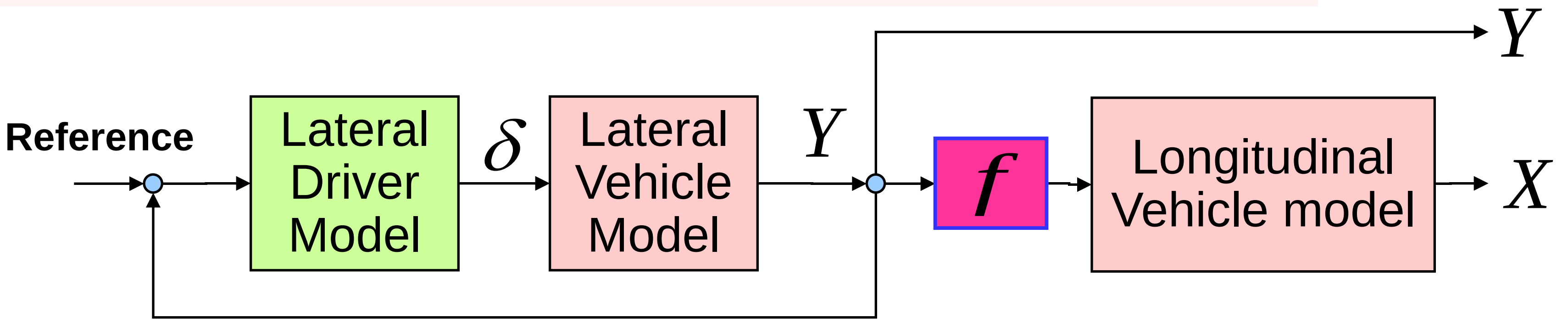


Motivation of $Y \rightarrow \boxed{f} \rightarrow X$

(academic viewpoint)

Combination driver model

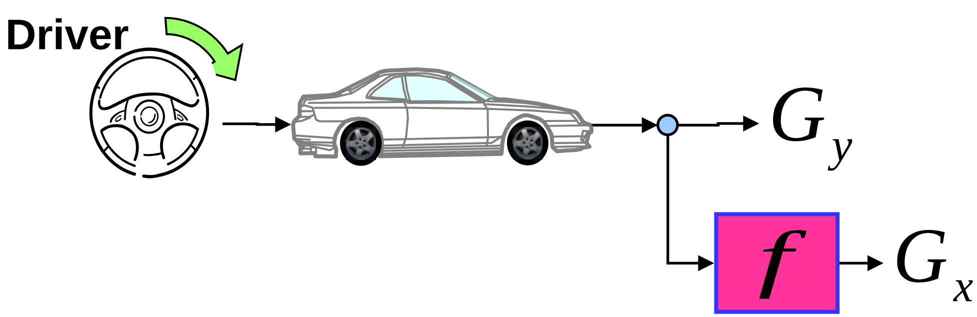
Driver's accel./decel. in coordination with lateral motion



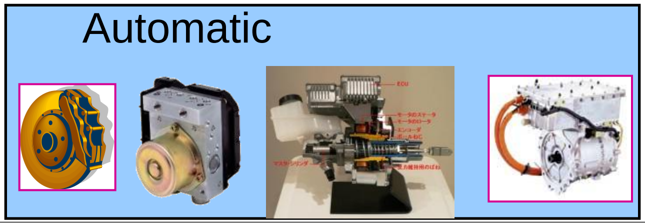
(industrial viewpoint)

Automatic longitudinal acceleration control system

Smooth and comfortable control in accordance with steering action



G-Vectoring



Summary of our previous study

I am very sorry to skip the deriving process··

$Y \to \boxed{f} \to X$

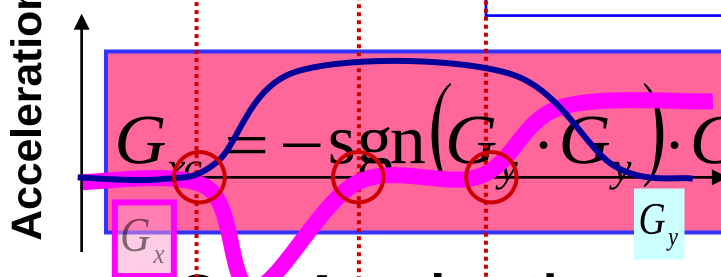
Jerk :First derivative of acceleration

Braking & steering start ⇔ Lateral jerk = 0

Braking stop ⇔ Lateral jerk = 0

Acceleration start ⇔ Lateral jerk = 0

A basic longitudinal motion control strategy for coordination with lateral motion



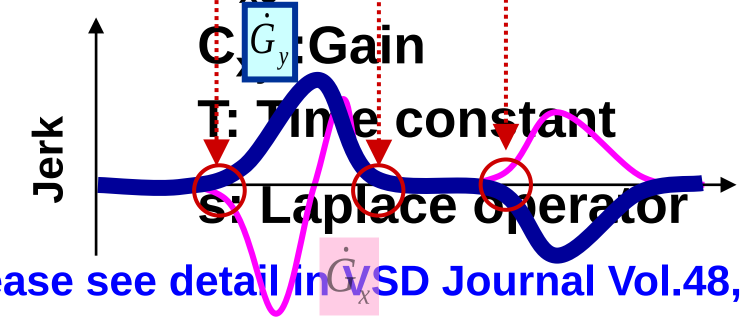
$$G_{xc} = -\mathrm{sgn}(G_y \cdot \dot{G}_y) \cdot C_{xy}$$

G_{xc} : Acceleration comm

C_{xy}:Gain

T: Time constant

s: Laplace operator



Longitudinal acceleration has strong relationship with lateral jerk.

$$\dot{G}_y \to \boxed{f} \to G_x$$

Please see detail in VSD Journal Vol.48, Supplement pp 231-254 (2010)

Previous studies

$Y \rightarrow f \rightarrow X$

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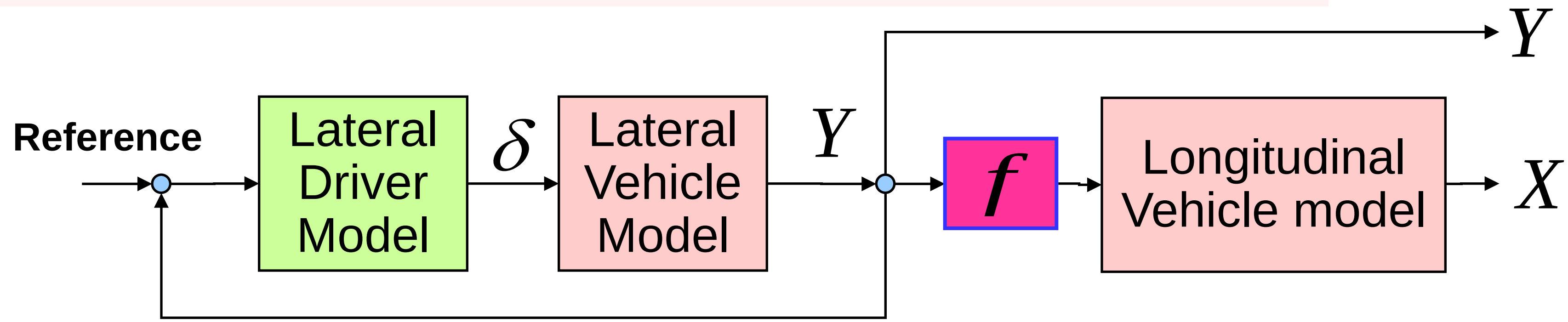
(academic viewpoint)

Combination driver model

Driver's accel./decel. in coordination with lateral motion



(industrial viewpoint)

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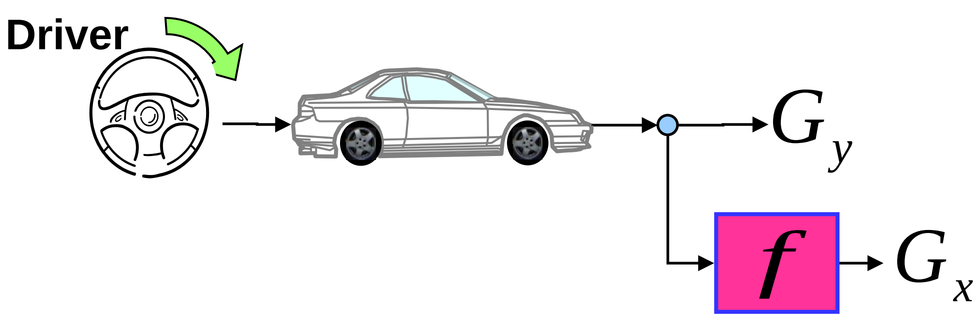
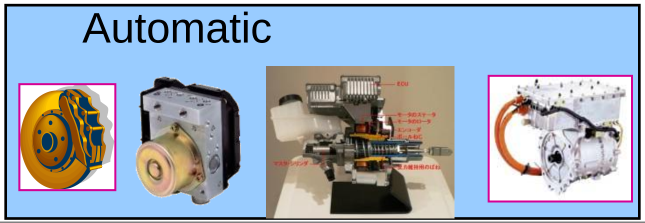


G-Vectoring



Combination driver model

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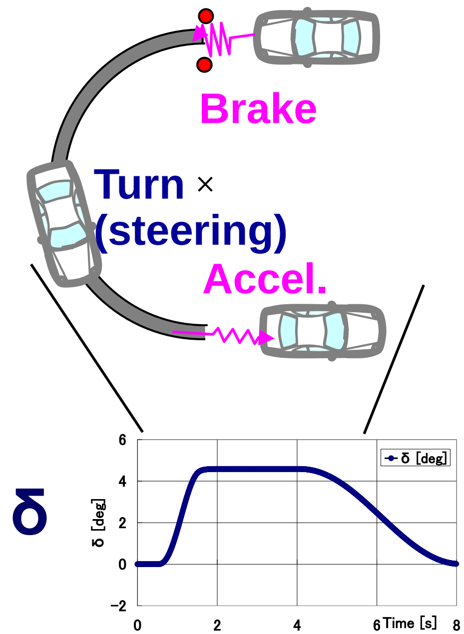
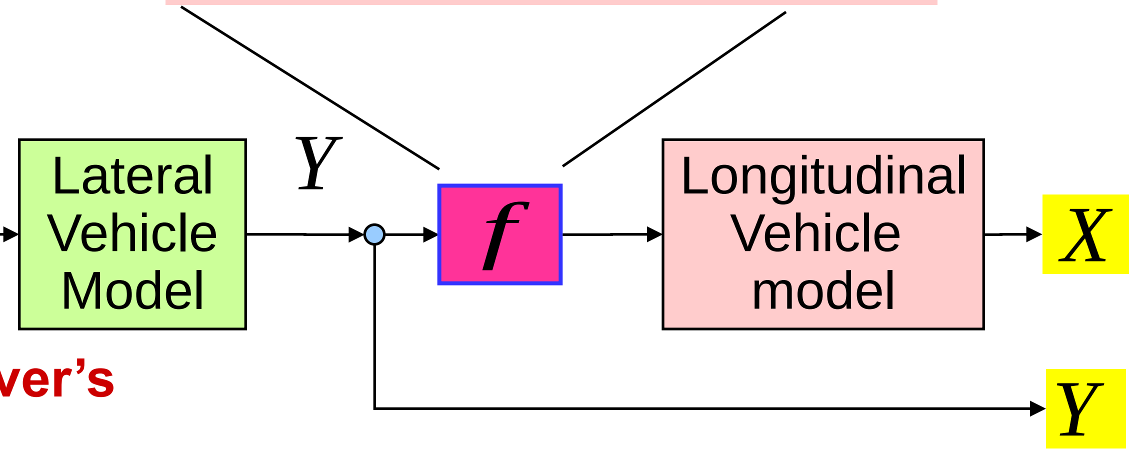
$Y \rightarrow \boxed{f} \rightarrow X$

Vehicle test by Expert driver



$$G_x = -\mathrm{sgn}\left(G_y \cdot \dot{G}_y\right)\frac{C_{xy}}{1+Ts}\left|\dot{G}_y\right|$$



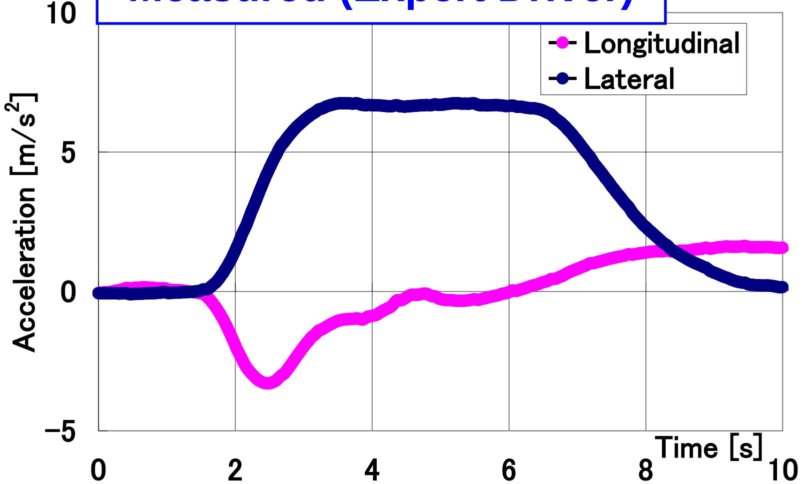
Using measured expert driver's Steering angle

Lateral Vehicle model: Bicycle model with nonlinear tire characteristics

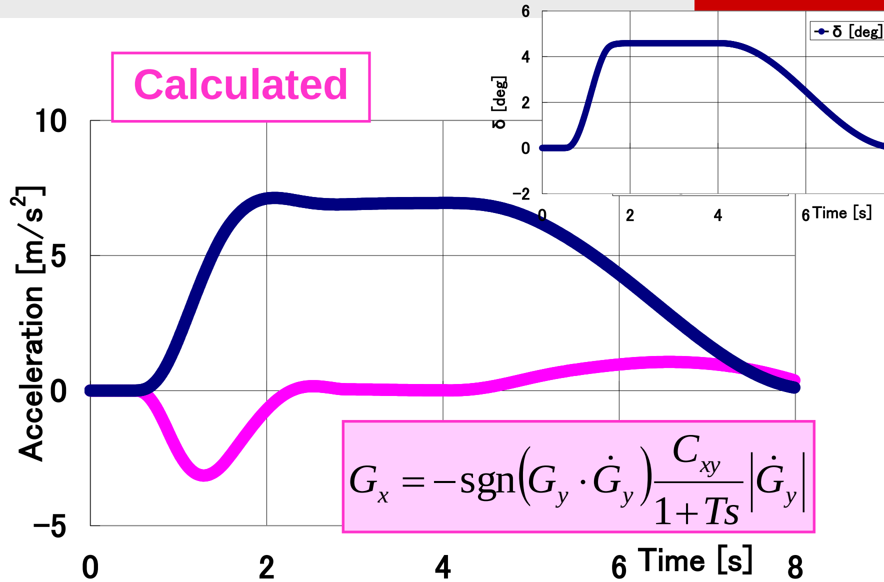
(We also tried preview follower model to evaluate the model. Please see detail in VSD Journal Vol.46(S1), 129-149 (2007))

Comparison between driver and proposed model

Measured (Expert Driver)



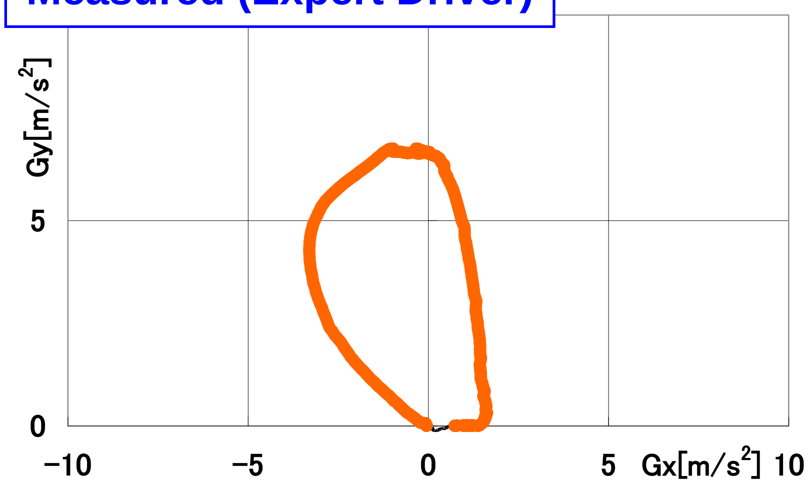
Calculated



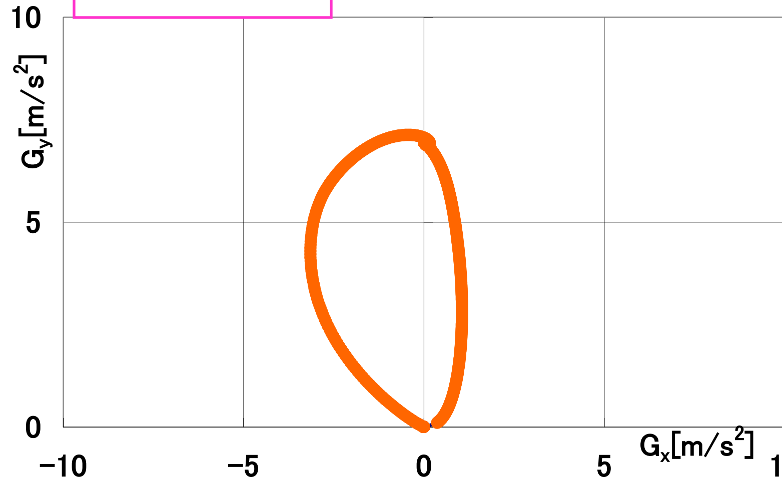
$$G_x = -\mathrm{sgn}\left(G_y \cdot \dot{G}_y\right)\frac{C_{xy}}{1+Ts}\left|\dot{G}_y\right|$$

$C_{xy} = 0.4 \quad T = 0.1$

Measured (Expert Driver)



Calculated



Possible to emulate part of an expert driver's coordination control strategy.

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3. Evaluation of G-Vectoring control
    1. Brake GVC
    2. Motor GVC
    3. GVC with ESC
4. Summary

Previous studies

$Y \rightarrow \boxed{f} \rightarrow X$

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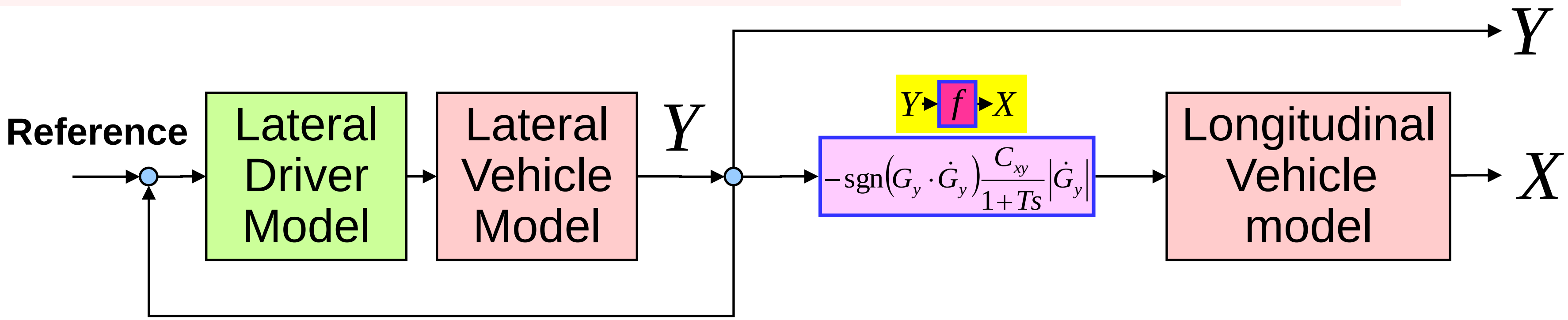
(academic viewpoint)

Combined driver model

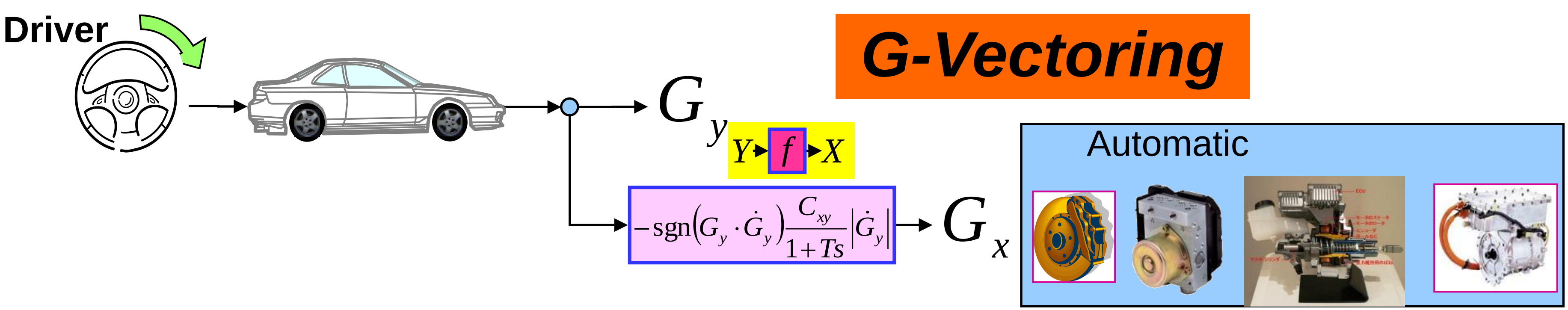
Driver's accel./decel. in coordination with lateral motion



(industrial viewpoint)

Automatic longitudinal acceleration control system

Smooth and comfortable control in accordance with steering action



Intuitive understanding of G-Vectoring

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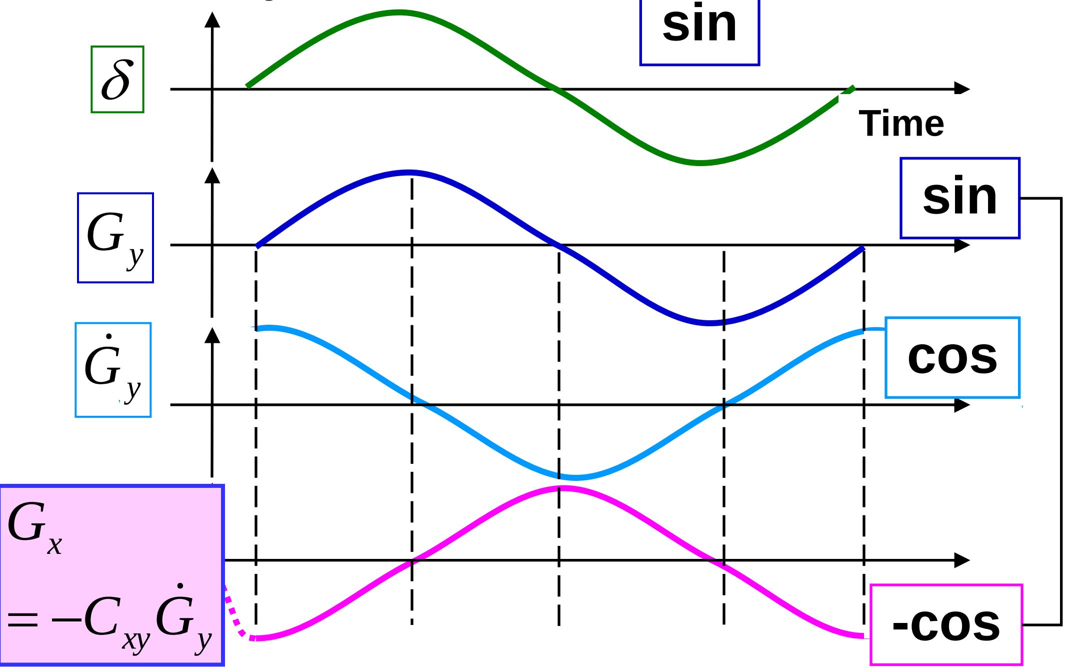
$$G_x = -\mathrm{sgn}\left(G_y \cdot \dot{G}_y\right)\frac{C_{xy}}{1+Ts}\left|\dot{G}_y\right| \Rightarrow G_x \approx -C_{xy}\dot{G}_y$$

Longitudinal acceleration is controlled to be proportional to lateral jerk caused by steering action.

$$\begin{cases} G_y = |G|\sin\gamma \\ G_x = -C_{xy}\dot{\gamma}|G|\cos\gamma \end{cases}$$

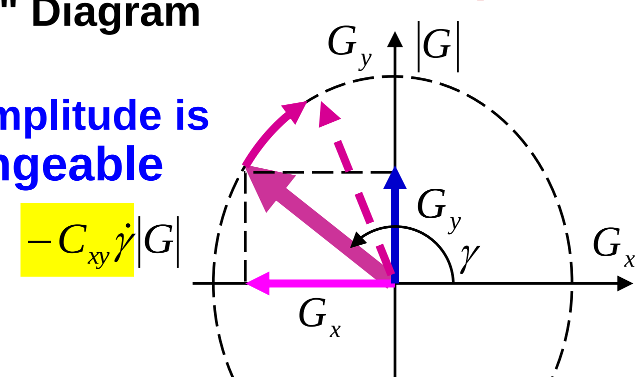
Time history



Oval expression

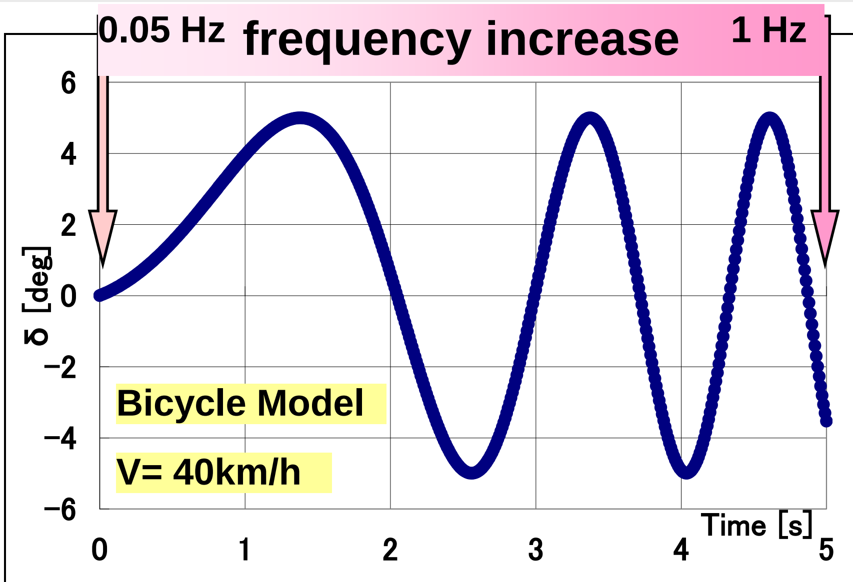
"g-g" Diagram

Gx amplitude is Changeable



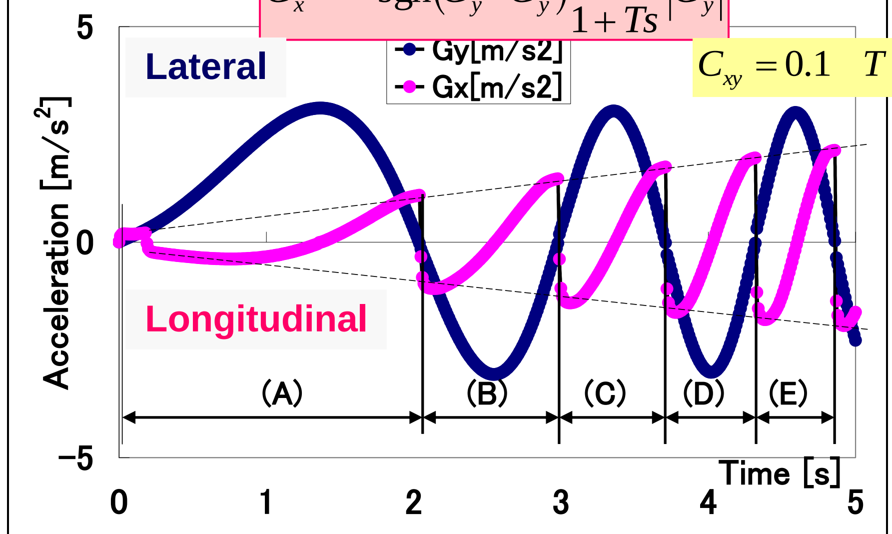
Resultant acceleration changes direction seamlessly

Vectoring feature of resultant acceleration G



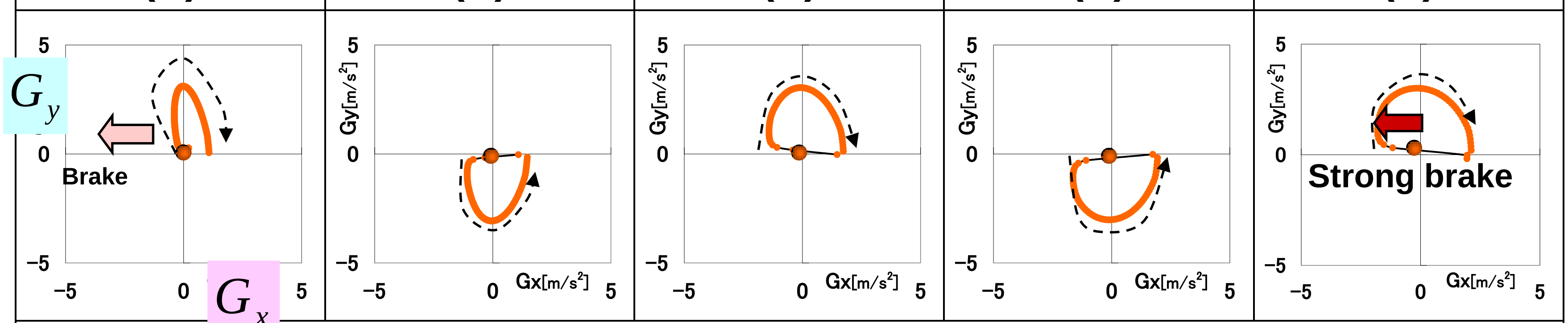
$$G_x = -\mathrm{sgn}\left(G_y \cdot \dot{G}_y\right)\frac{C_{xy}}{1+Ts}\left|\dot{G}_y\right|$$

$C_{xy} = 0.1 \quad T = 0.1$



Steering angle	Accelerations

(A)	(B)	(C)	(D)	(E)



Steering Speed increase → Strong Brake *will be applied automatically*

(No need to have steering speed map data)

Vehicle speed and G-Vectoring feature

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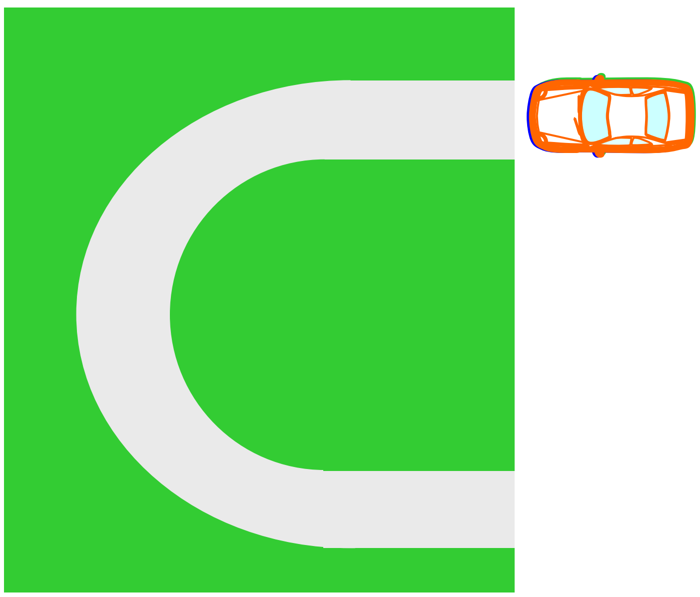
<u>**Situation**</u>
Goes into same corner in difference speed

G-Vectoring "g-g" diagram

V = 50〜70km/h

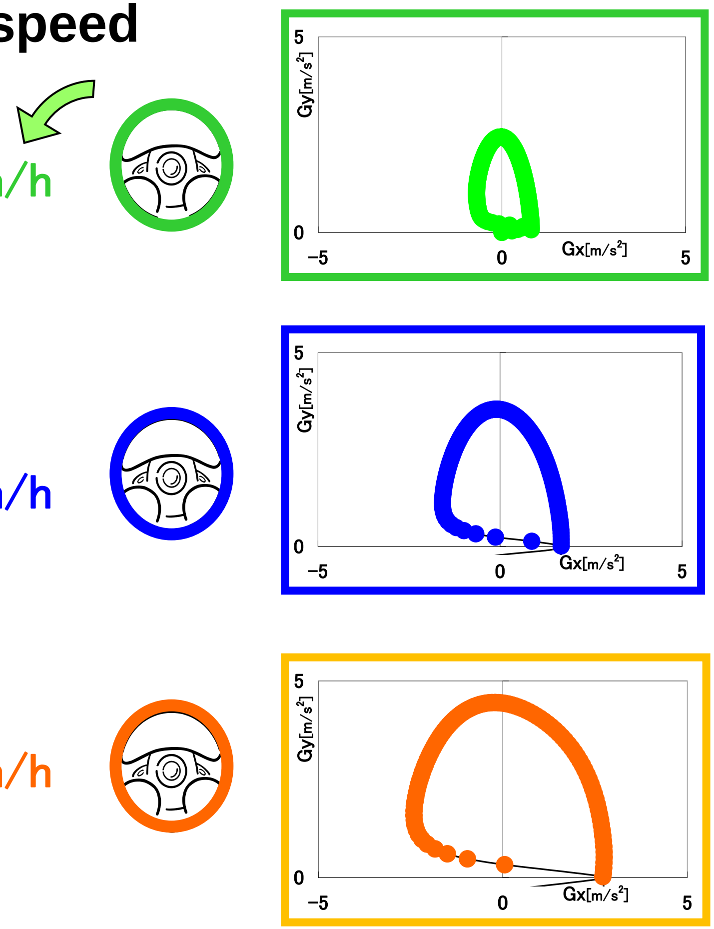
Curved Course



V = 50km/h

V = 60km/h

V = 70km/h

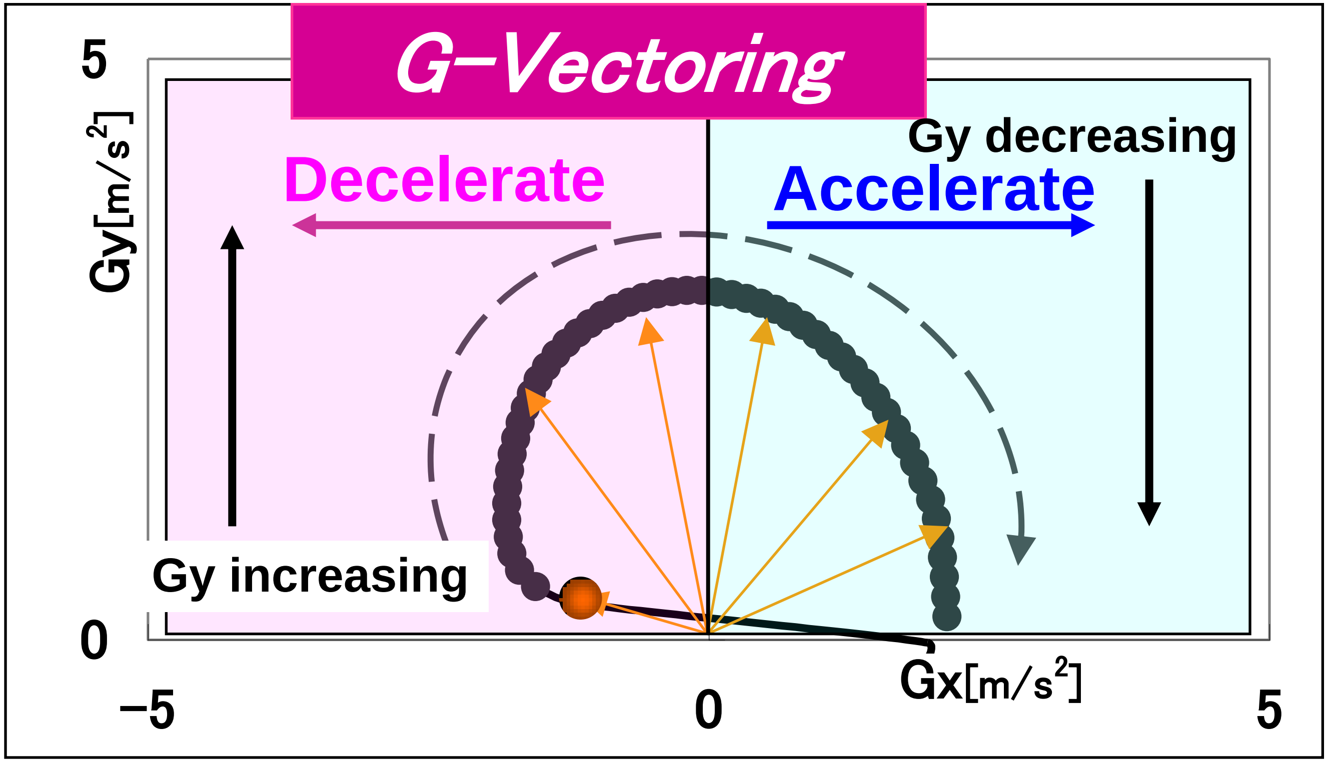


With G-Vectoring Control,

Entering Speed increase → Strong Brake ***will be applied automatically***
(No need to have vehicle speed map data)

Once Again!
Vectoring feature of resultant acceleration G

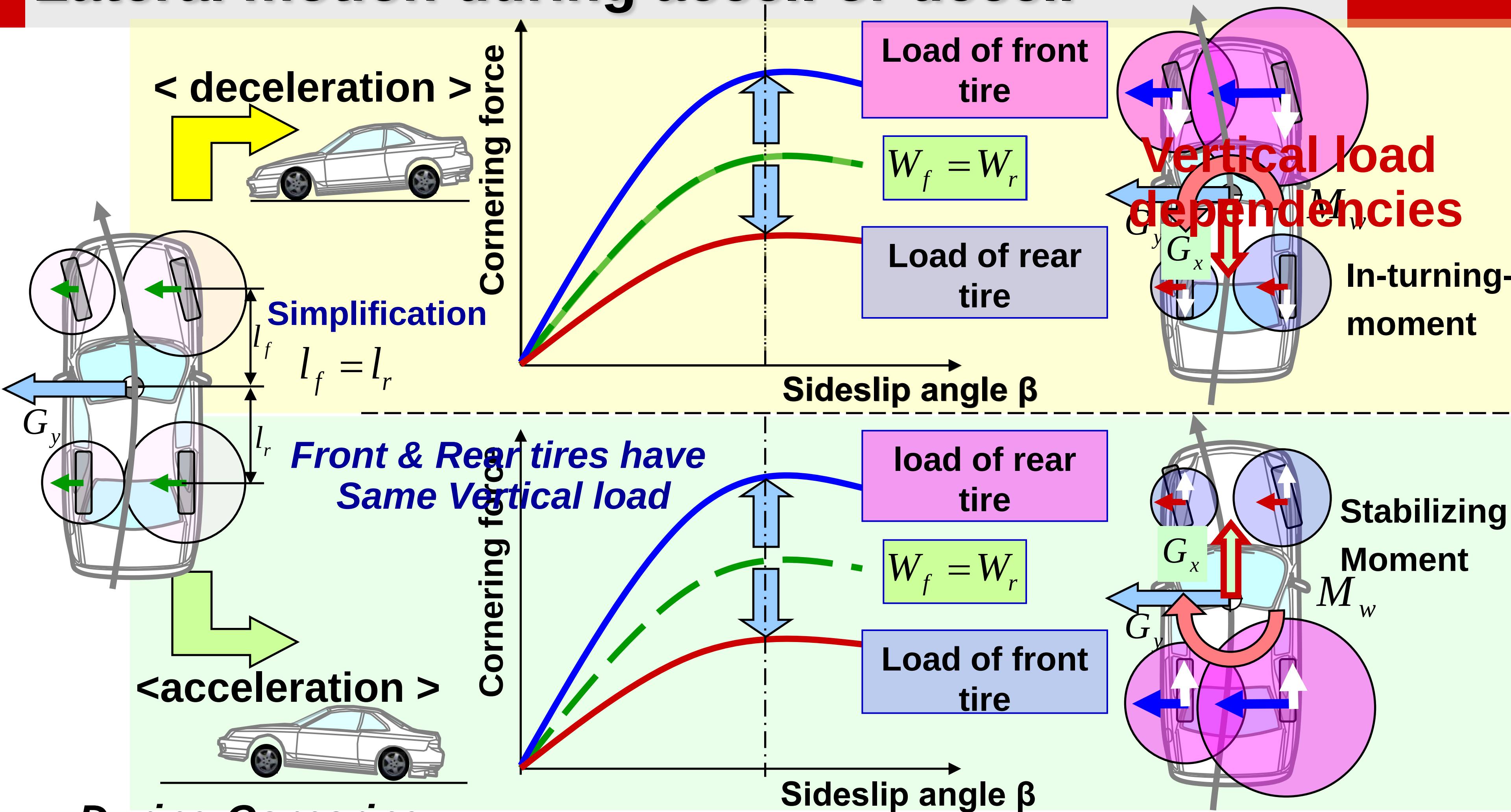
$$G_x \approx -C_{xy}\dot{G}_y$$



Gy increasing: Decelerate , Gy decreasing: Accelerate

Deceleration at Gy increasing, acceleration at Gy decreasing

Lateral motion during accel. or decel.



During Cornering,

■Deceleration → In-turning-moment → Agility

■ Acceleration → Stabilizing moment → Stability

Overview of G-Vectoring controlled vehicle

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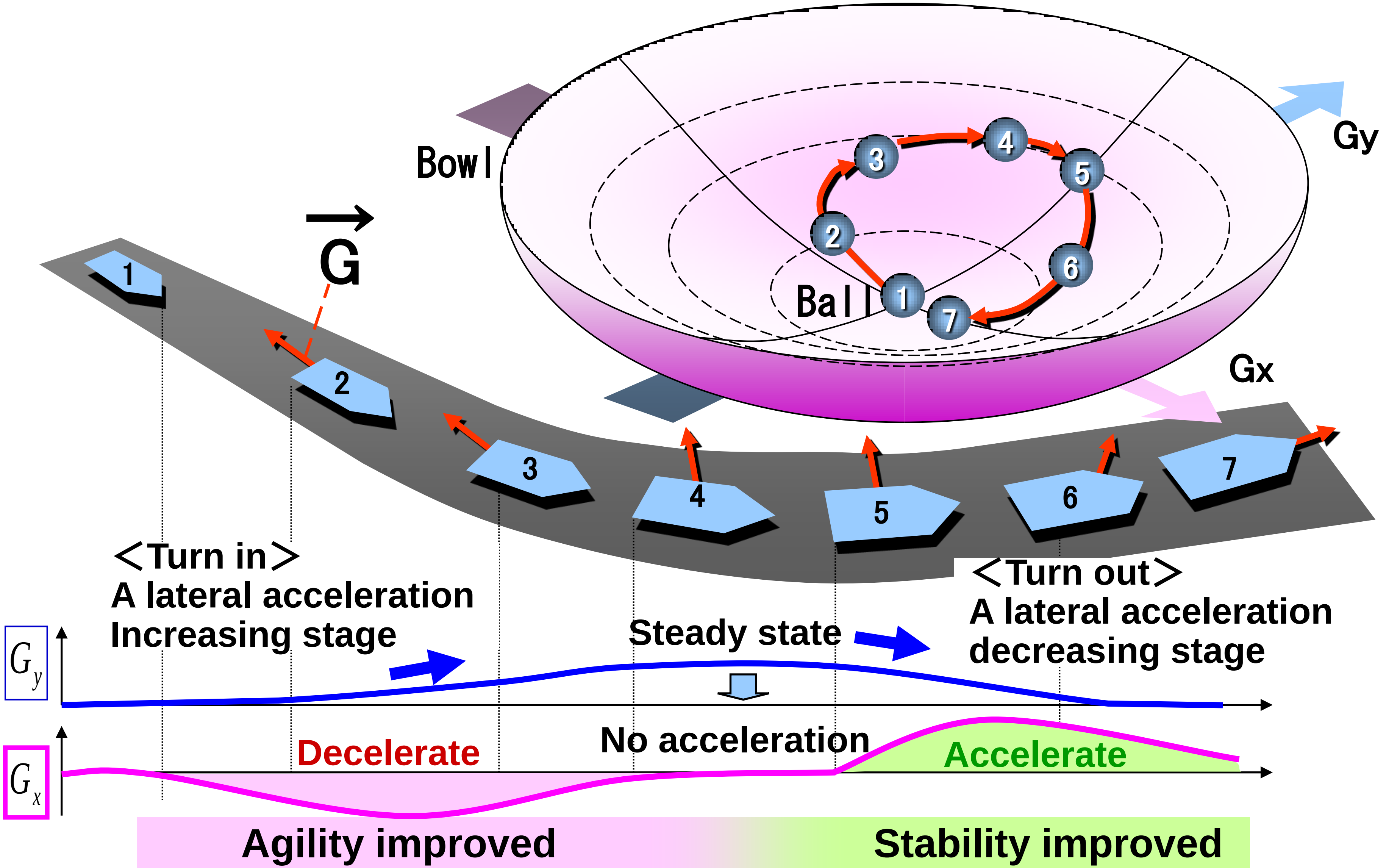

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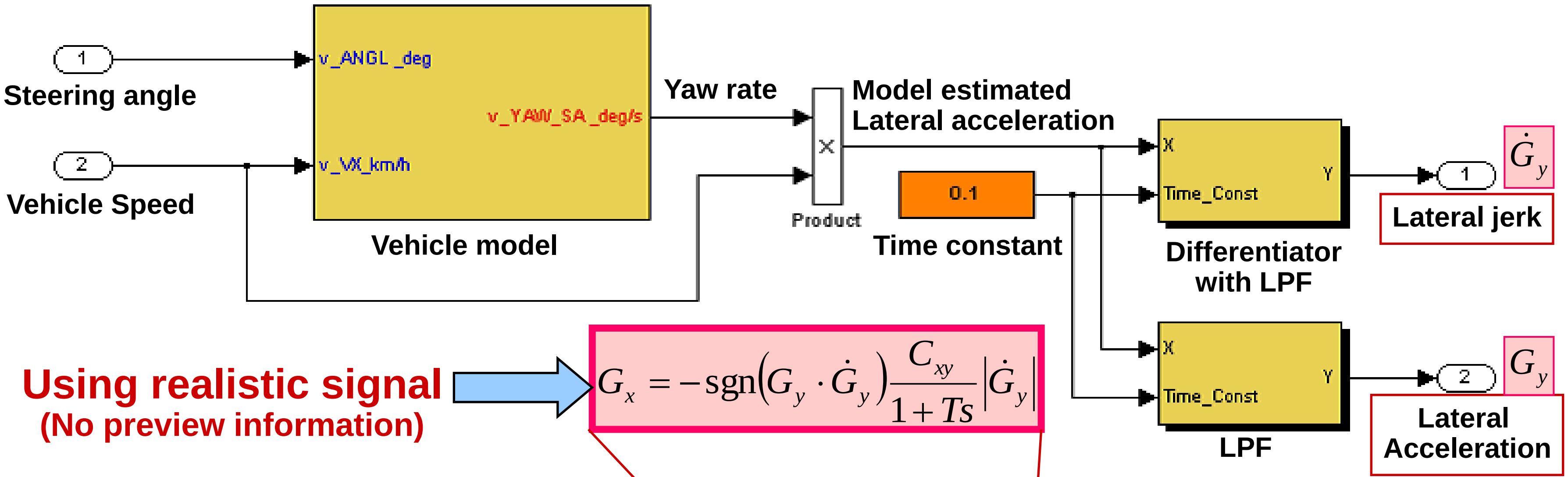
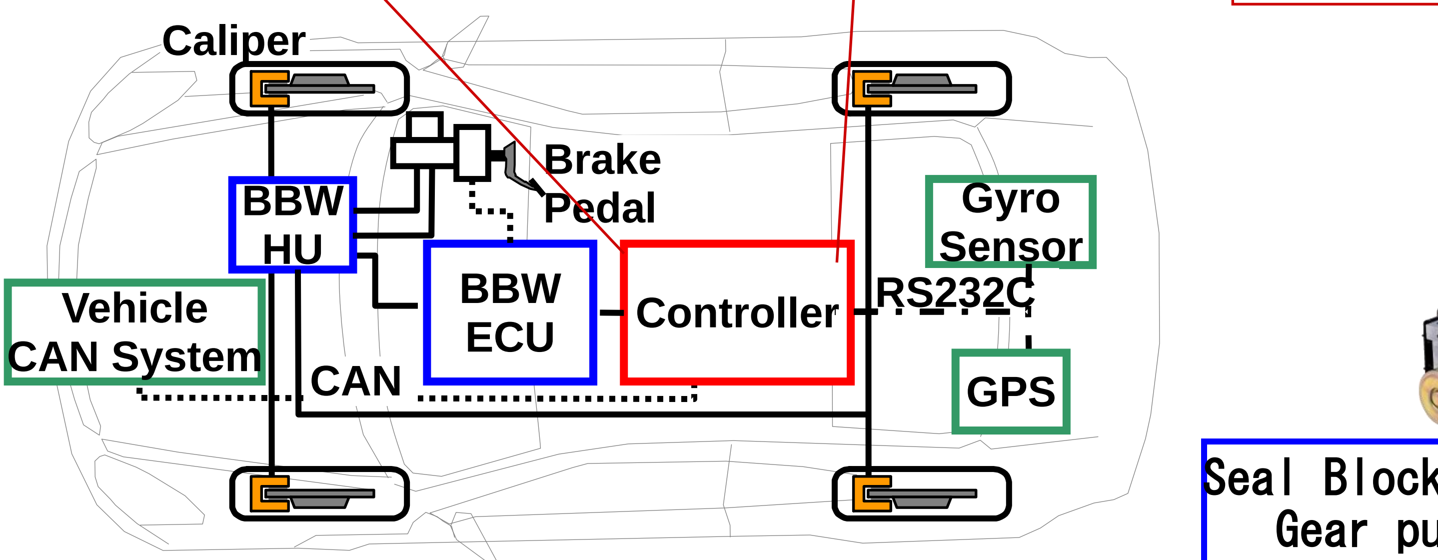
Overview of experimental vehicle



Using realistic signal
(No preview information)

$$G_x = -\mathrm{sgn}(G_y \cdot \dot{G}_y)\frac{C_{xy}}{1+Ts}\left|\dot{G}_y\right|$$



Seal Block type Gear pump

L&R Brake Force distribution function was not used.→NO DYC

Cornering performance evaluation scenario

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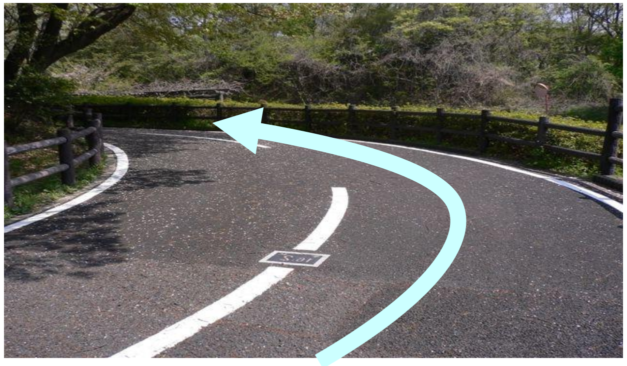
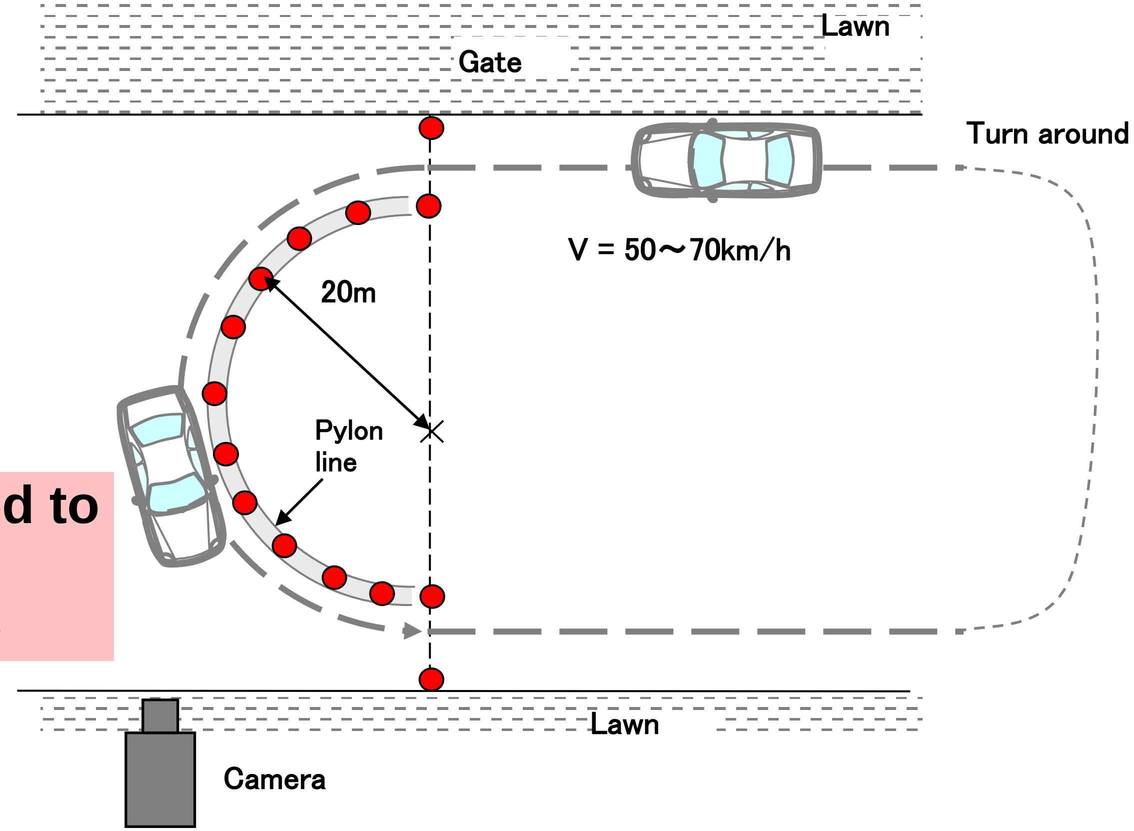
Assumption :
Driver enters a blind corner at high speed, and the curvature is tighter than expected.

Normal Driver's Action
-Cannot apply adequate brake
-Just increase steering angle

Blind corner



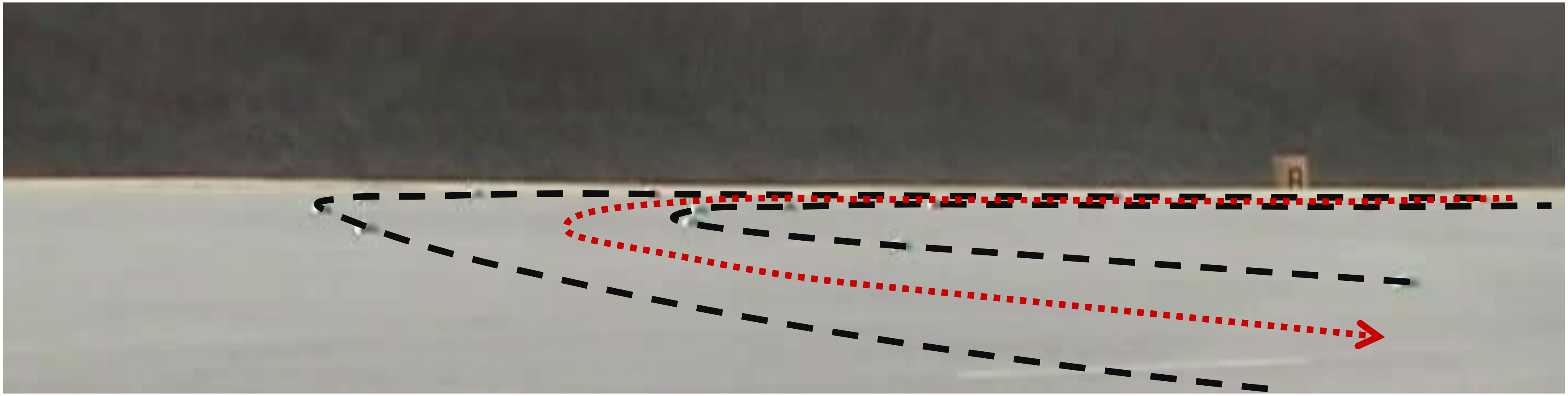
Test menu



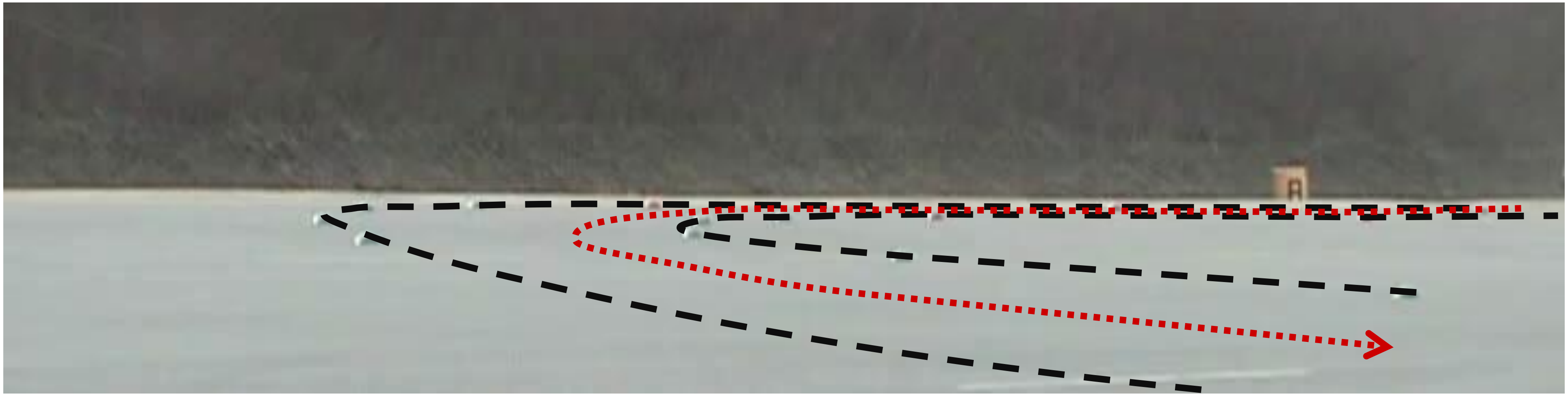
Driver was ordered to
-No braking
-Follow pylon line

Cornering performance at 70km/h

Without Control video



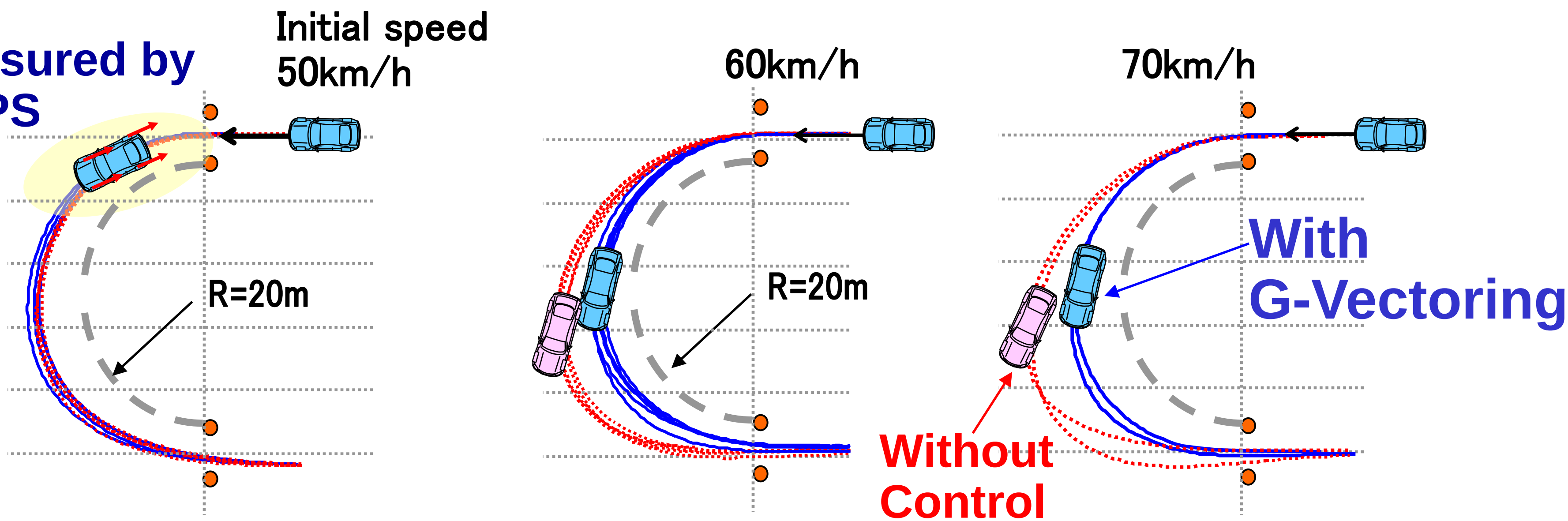
With G-Vectoring video



Evaluation of traceability

Without Control **With G-Vectoring**

Measured by DGPS



<u>**G-Vectoring**</u>

Effective to maintain traceability

Steering angle versus yaw rate evaluation

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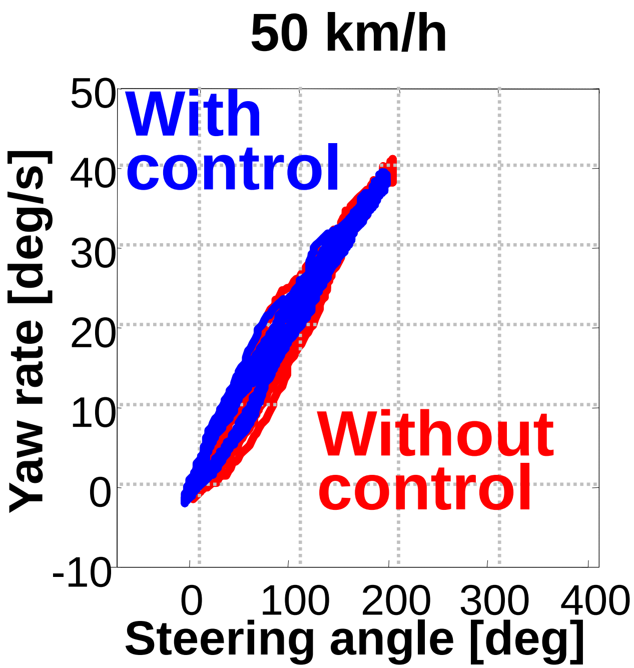
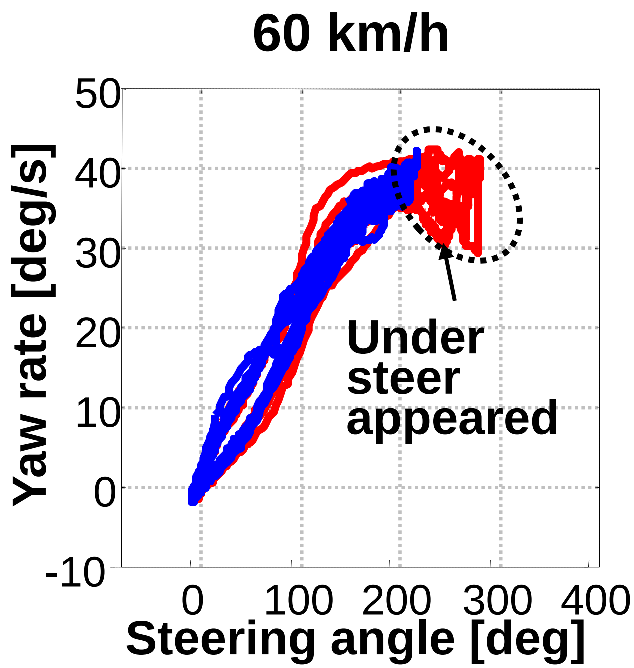
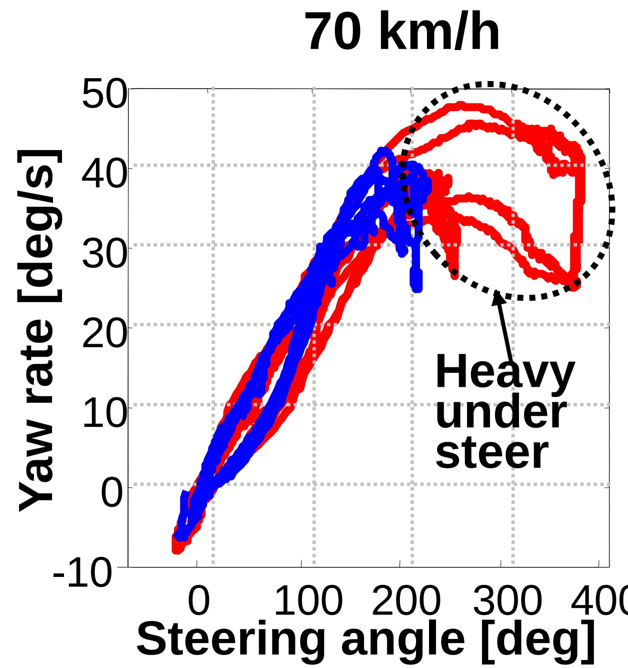


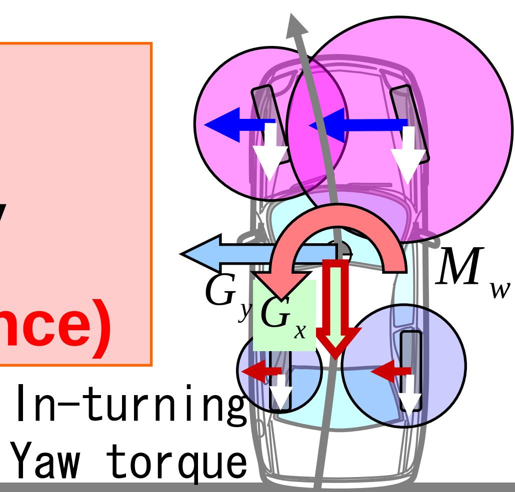




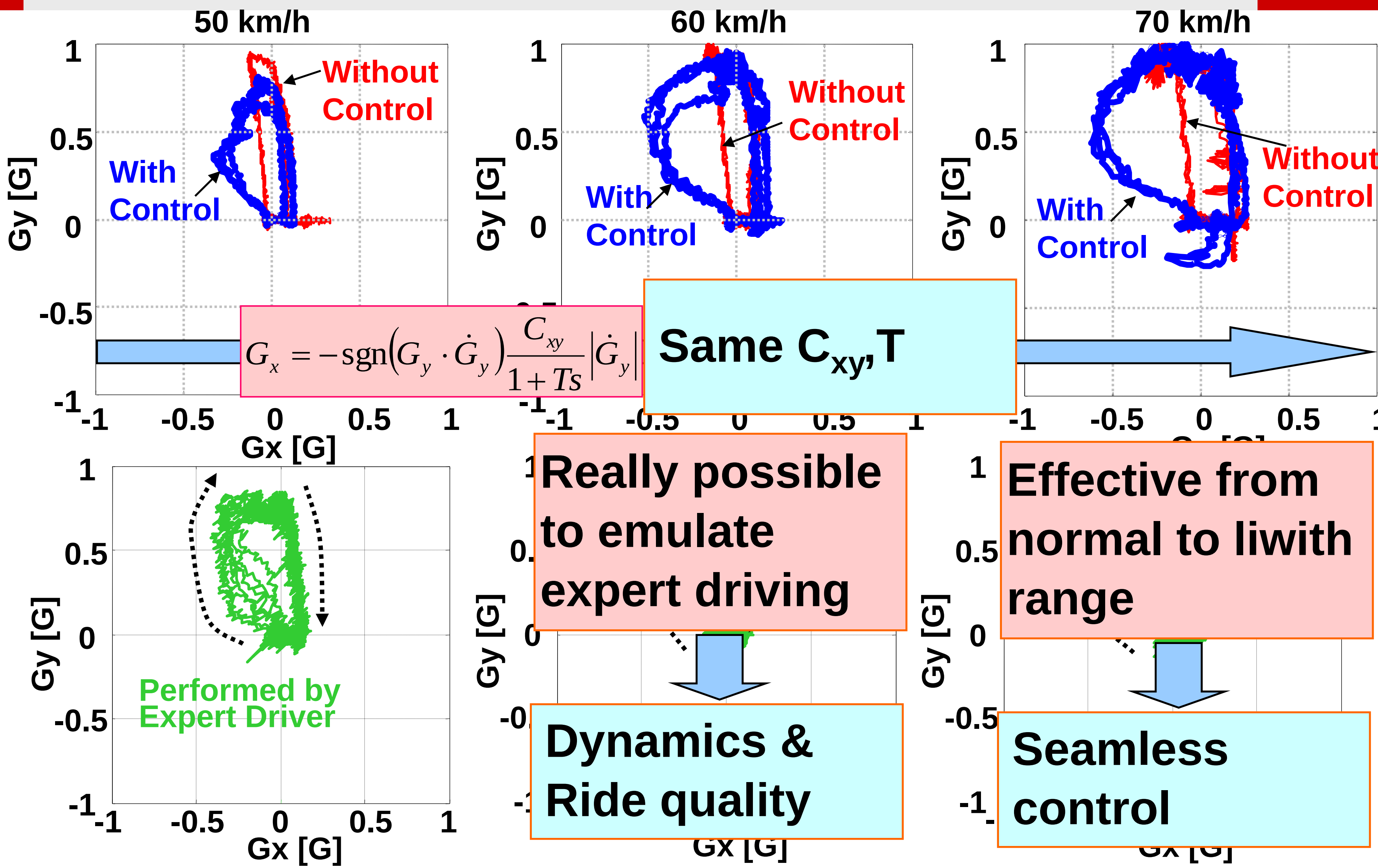
<u>**G-Vectoring**</u>

Effective to maintain linearity

(Excellent under steer prevention performance)



“g-g” diagram evaluation



$$G_x = -\mathrm{sgn}\left(G_y \cdot \dot{G}_y\right)\frac{C_{xy}}{1+Ts}\left|\dot{G}_y\right|$$

Same C_{xy},T

Really possible to emulate expert driving

Dynamics & Ride quality

Effective from normal to liwith range

Seamless control

Vertical load shift image of G-Vectoring

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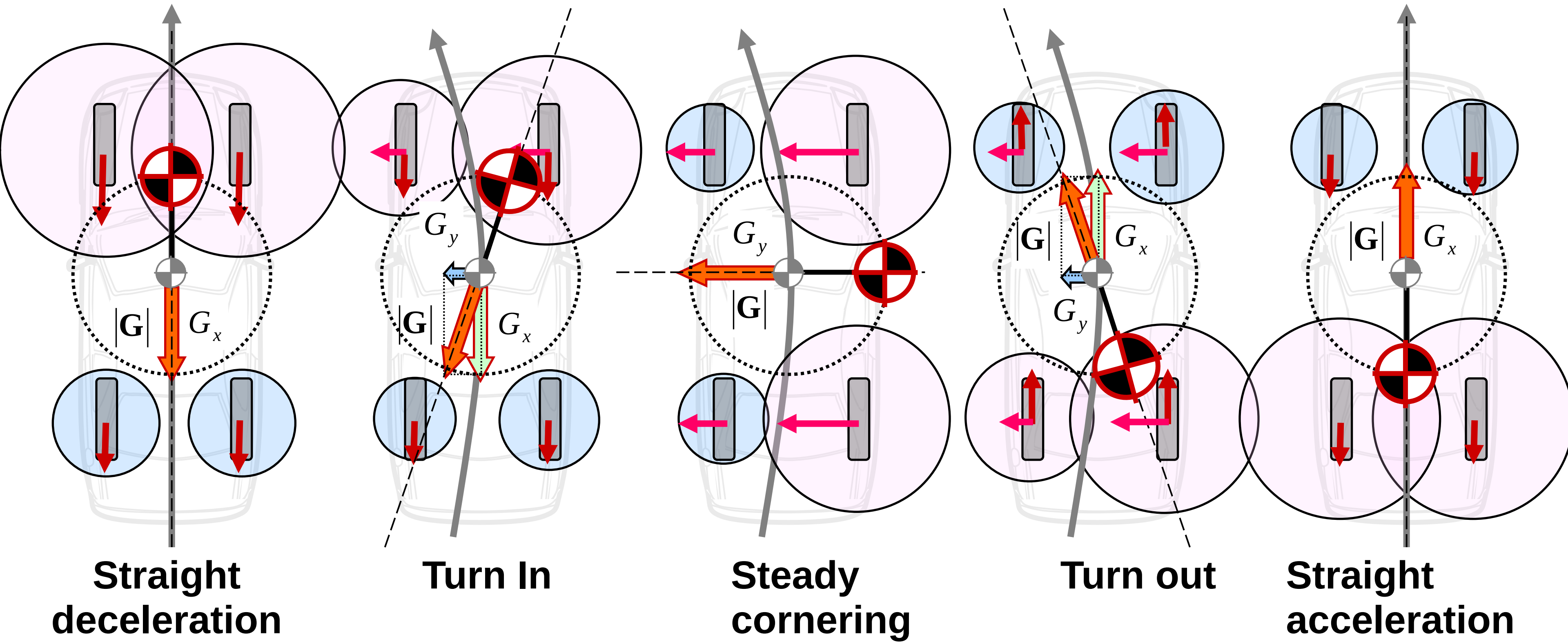

A resultant acceleration changes as the vertical load applies on an important tire at each stage.

Cooperation of pitch and roll can be achieved.

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Specification of Test EV

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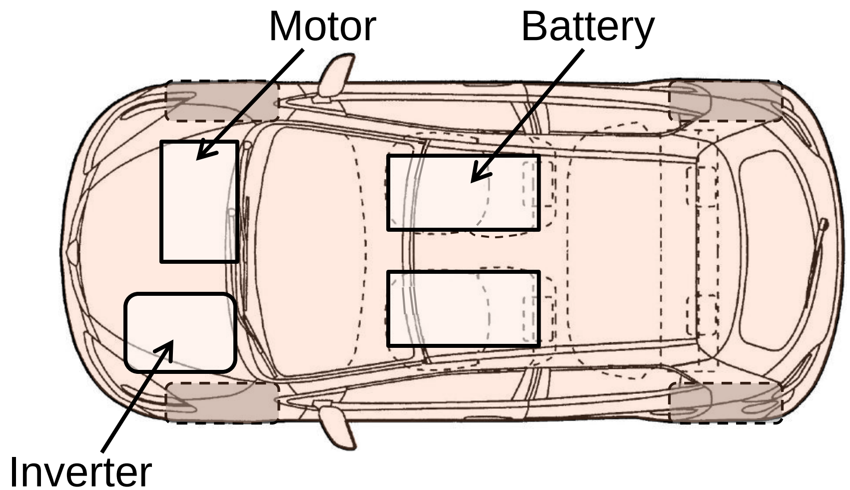
Specification

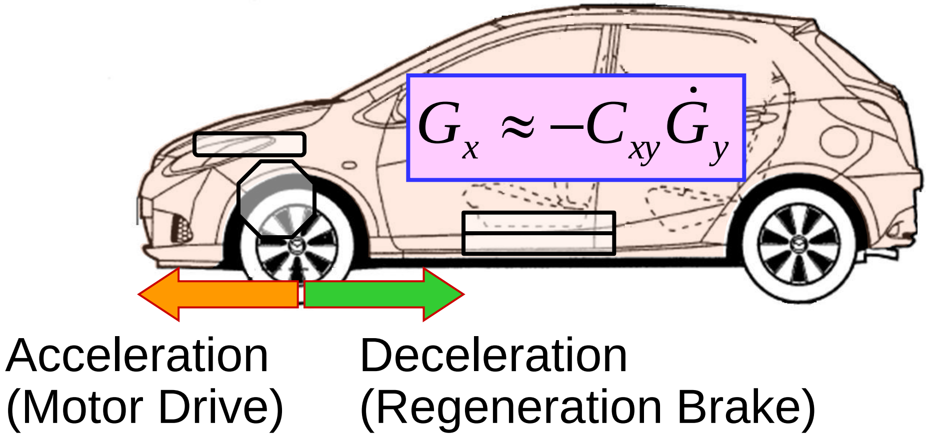
Base vehicle		Mazda 2 (08 year model)
Motor	Type	Permanent magnet type synchronous motor (water-cooled)
	Rated voltage	346 VDC
	Declared power	Continuousness: 11.5kW Maximum: 24kW
	Max torque	87 Nm
Battery	Type	Lithium ion (air cooling)
	Capacity	3.8 kWh

Configuration



Photo

Control



G-Vectoring by EV

Test of G-Vectoring by Electro-motor

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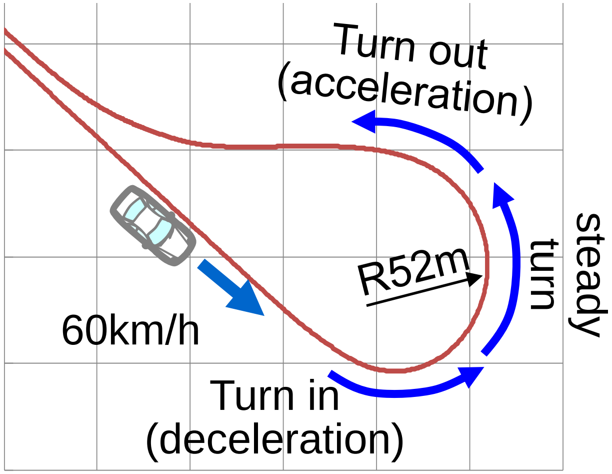
Course



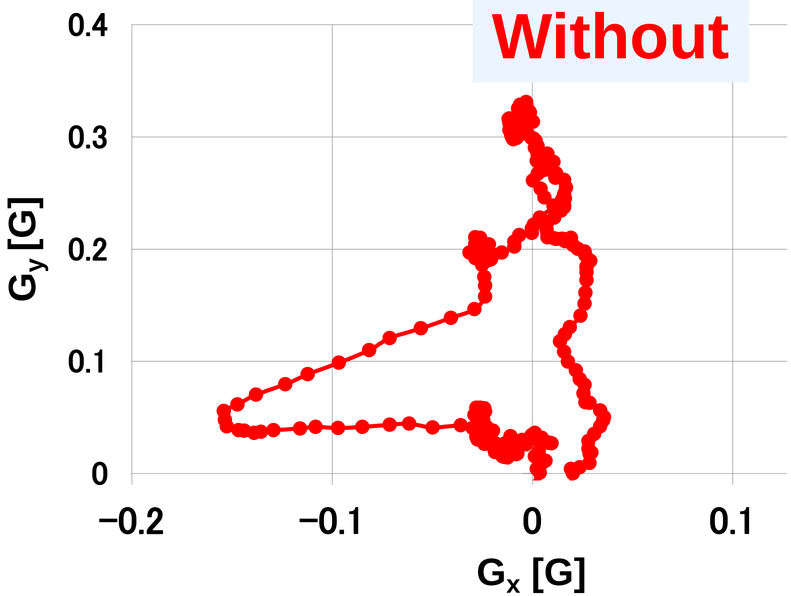
Experimental conditions

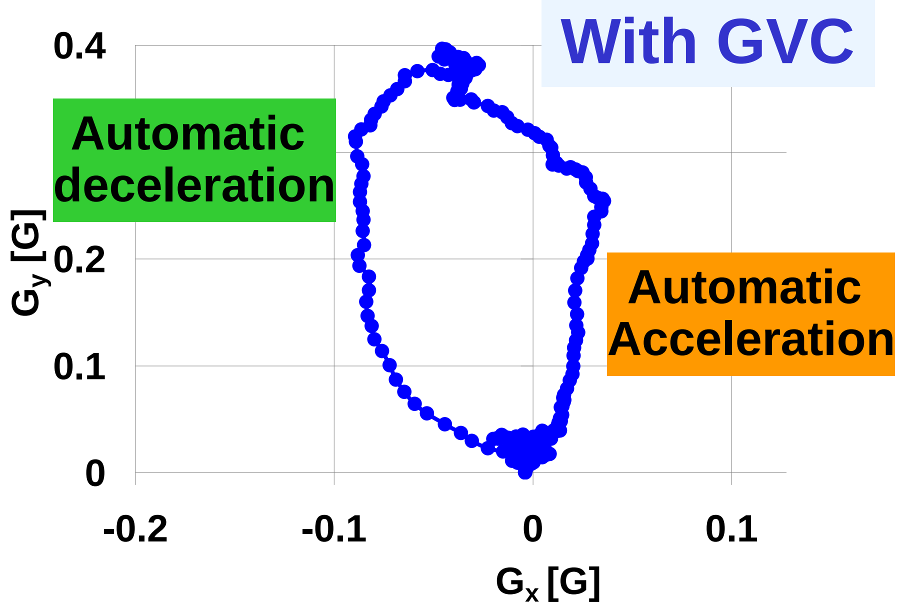
Without control

Operated by driver

With GVC

Only steering wheel is operated.
Acc.&Dec. are automatic operations.





Energy recuperation in cornering.

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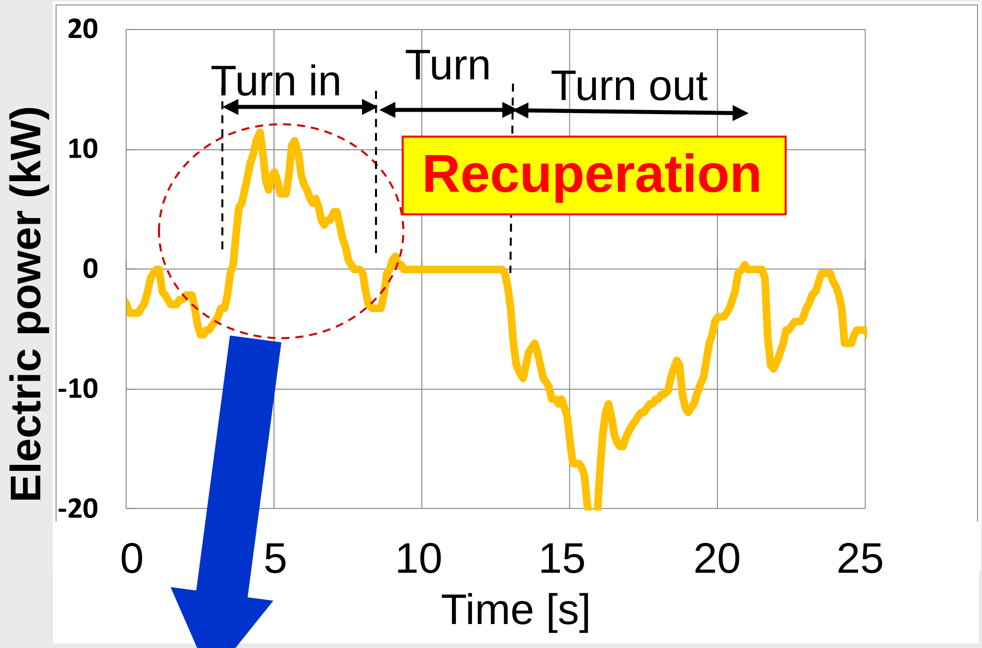
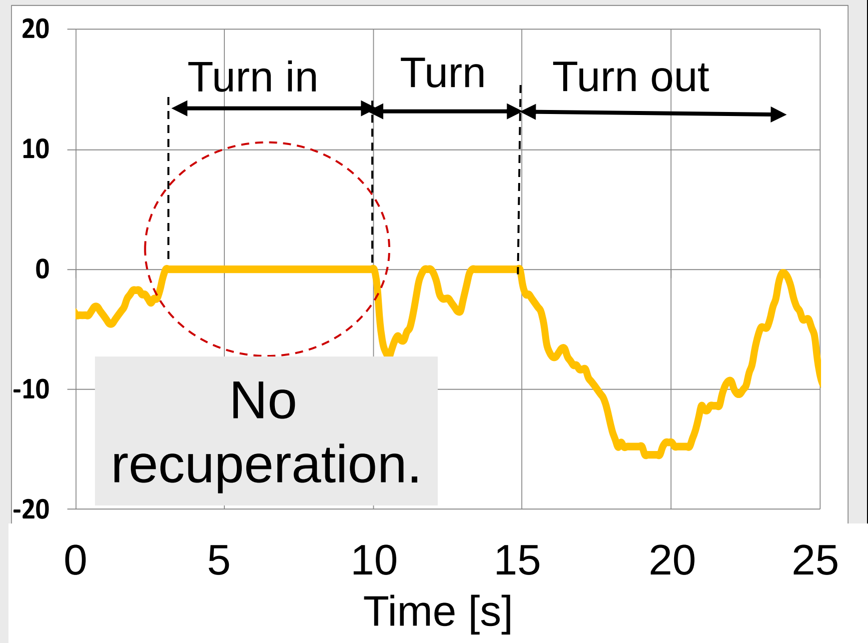
Without control



With GVC



Recuperation≒0.01kWh

Recuperates 0.01kW in cornering by GVC.
It is possible to drive ≒ about 100m longer.

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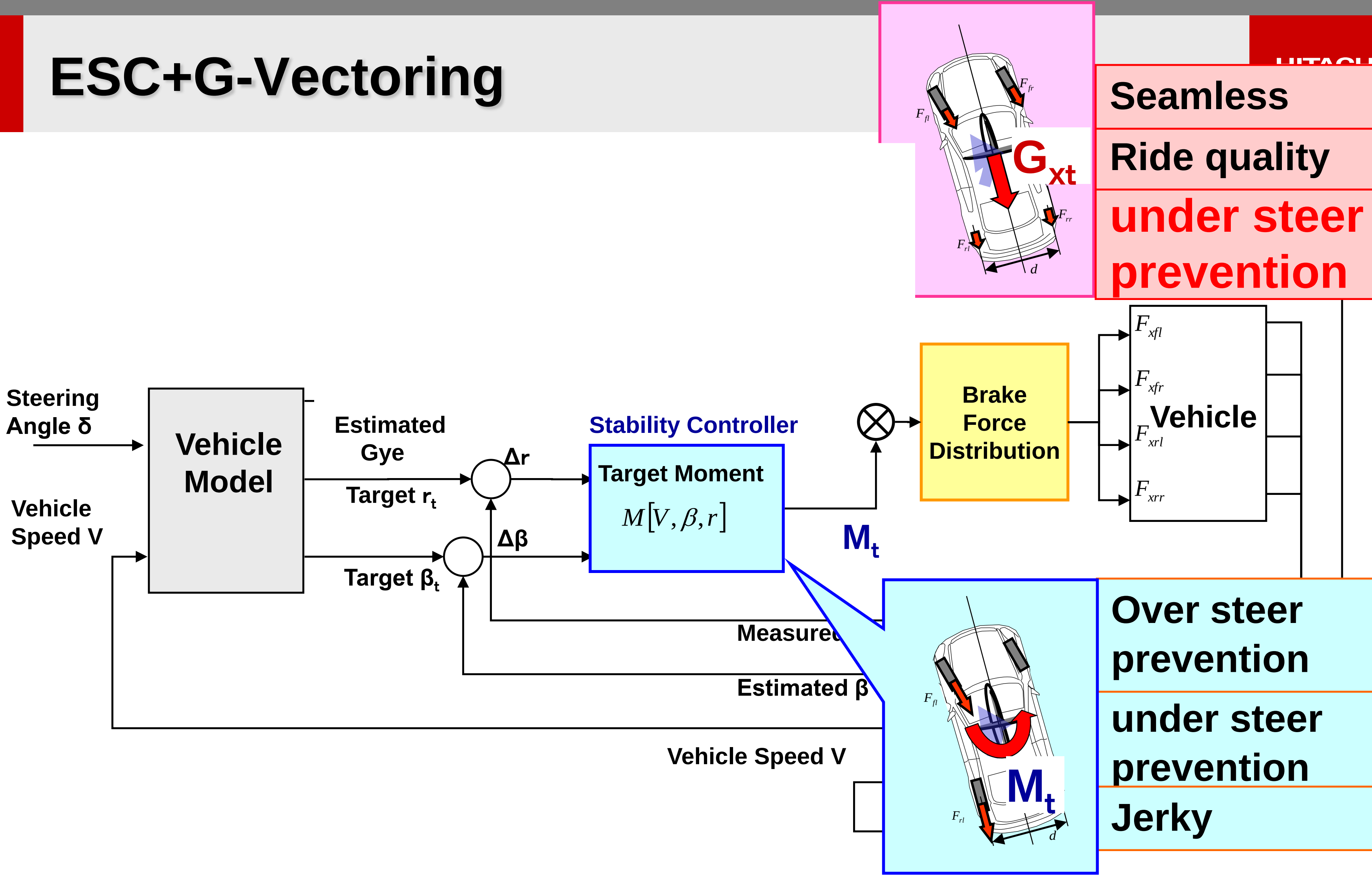
ESC+G-Vectoring



Using G-Vectoring as an agility controller

On Dry Asphalt (Hitachi Yamanashi PG)

Emergency lane change (90km/h)

Nur ESC

ESC with G-Vectoring

Brake light was modified to turn on during brake control

G-Vectoring can reduce the severe roll motion

(Excellent road holding performance)

Emergency lane change (90km/h) – Slow motion –

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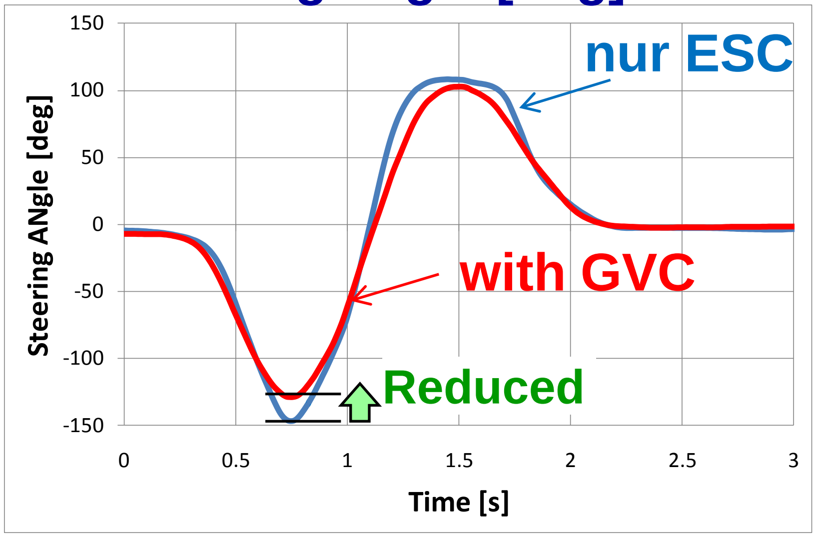
Nur ESC

ESC with G-Vectoring

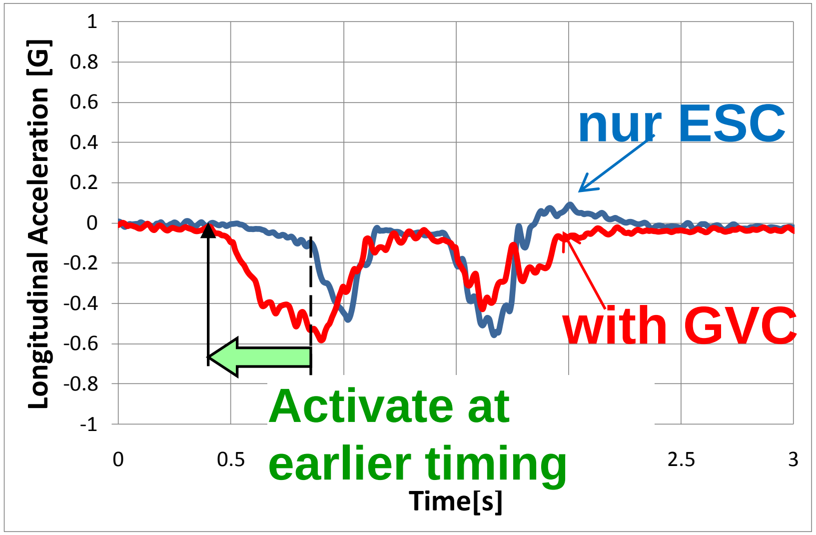
ESC with G-Vectoring activates earlier than ESC

Verification of time history data

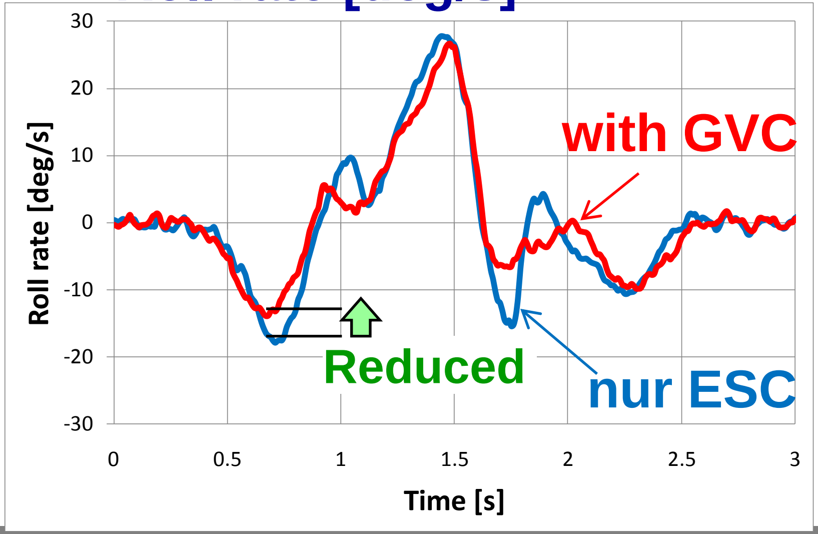
Steering angle [deg]



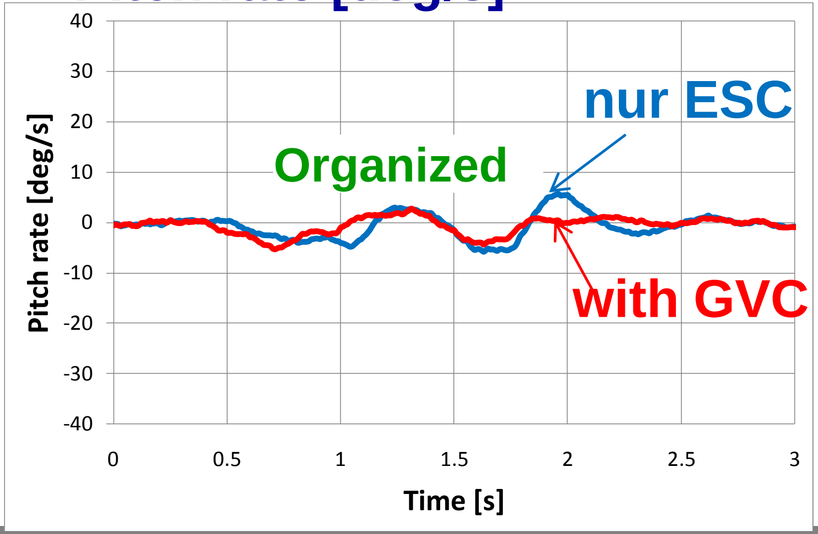
Longitudinal acceleration [G]



Roll rate [deg/s]



Pitch rate [deg/s]



On Slippery road (Hitachi Tokachi PG)

Test on slippery proving ground (J-Turn)

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Nur ESC | **ESC with G-Vectoring**

(with Over Slip Prevention control)

Improve traceability even on slippery surface

Driver’s maneuvers (J-Turn)

Nur ESC	ESC with G-Vectoring
	

Reduce the steering effort

Test on slippery proving ground (Lane Change)

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ESC Only

ESC&G-Vectoring

(with Over Slip Prevention control)

Improve lateral moving performance

Reduce maximum steering⇒Easy to stabilize

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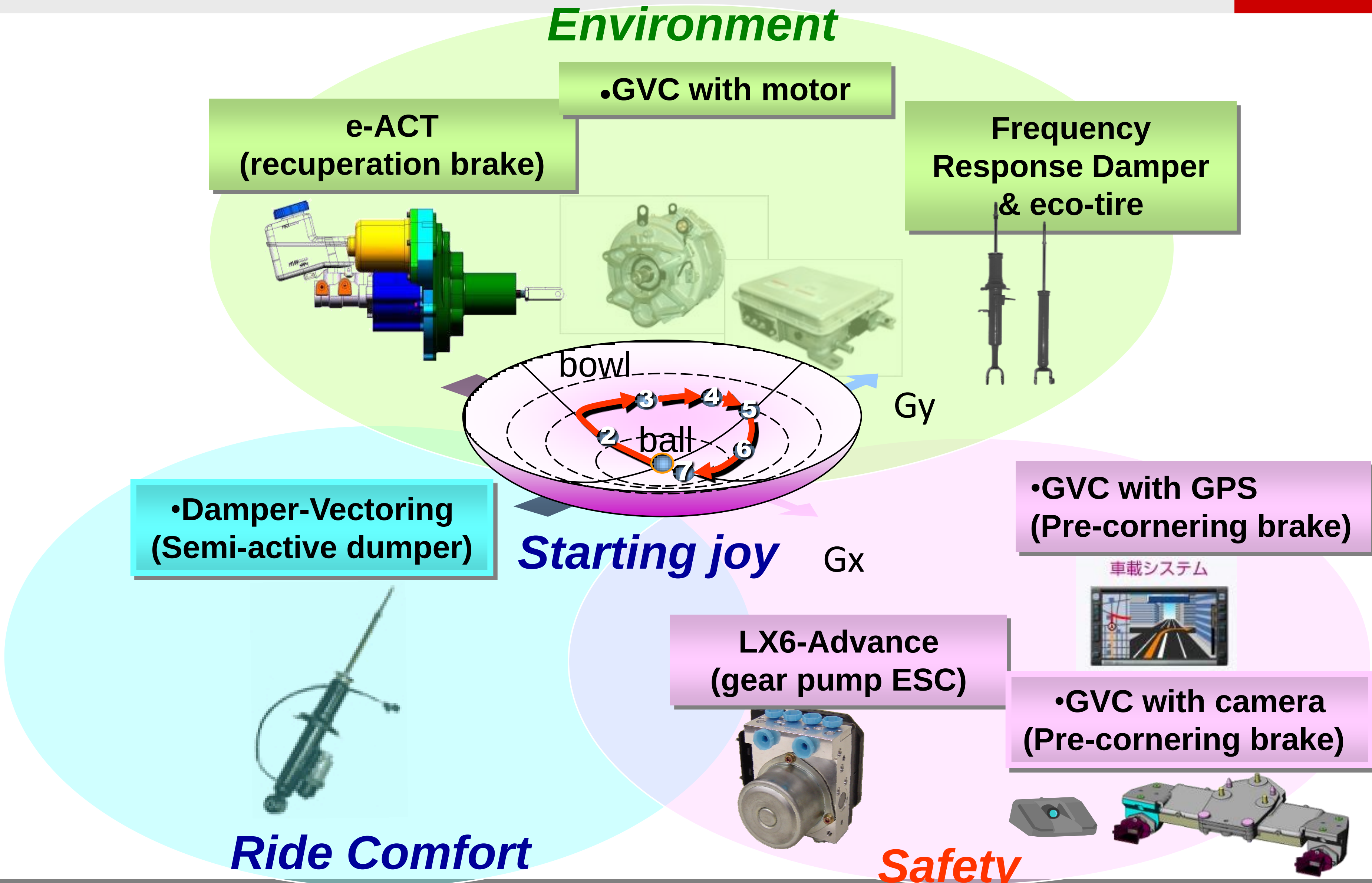
Summary

An experimental examination of G-Vectoring was conducted, and the following findings were obtained.

1. Really possible to emulate expert’s driving.
2. Effective from normal to liwith range.
3. Energy recuperation in cornering
4. *The ESC+GVC test results are **promising!***

Future G-Vectoring Control



Thank you for your kind attention!

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