

Development of Vehicle Control Technologies for Super Sport Model ZX-10R



With increasingly sophisticated engine and chassis performance, vehicle control technologies that assist the rider in steering are becoming increasingly important.

To achieve for riders a fun and easy ride, we equipped our international model ZX-10R SE with tailored wheelie control and electronic control suspension control to cater for such vehicle behavior.

Introduction

The development of autonomous driving is gaining momentum for passenger cars, and the time is nearing when autonomous driving will be put to practical use in limited environments, such as expressways. Autonomous driving is a conglomeration of control technologies, including environmental recognition, and is intended to eliminate driver's judgments and operations. In motorcycle development, however, autonomous driving is oriented in another direction.

1 Background

Kawasaki's motorcycles are by nature intended for

riders to enjoy driving. Seemingly, motorcycles do not require advanced controls. However, now that engine and chassis performance is much more sophisticated than it used to be, various control technologies have been adopted to achieve "ease of riding" and "a fun ride." These control technologies require intervention by riders (humans), so we are working to achieve "Rider-machine cooperative control," which is considered difficult to achieve with autonomous driving.

2 Control technologies for motorcycles

As shown in **Fig. 1**, control technologies for motorcycles have been developed for a long time, mainly for racing. Initially, controls were developed mainly to



Fig. 1 Road racing (World Superbike Championship)

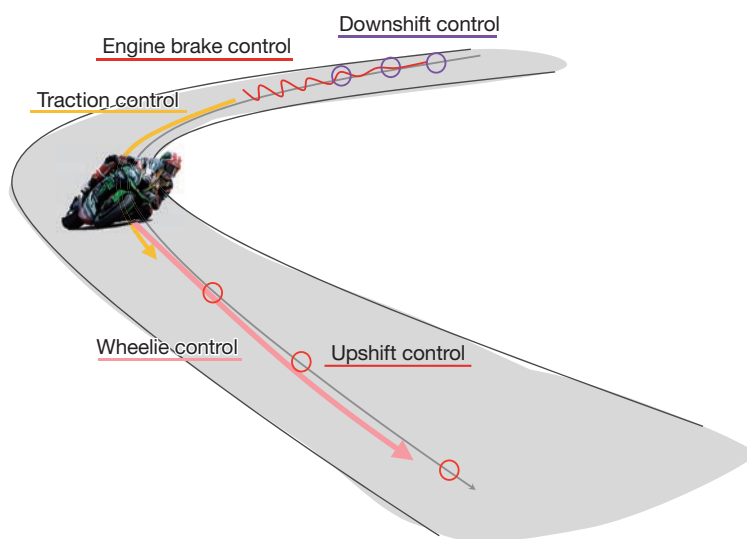


Fig. 2 Controls for racing situations

improve engine performance, and after engine performance was increased to a certain level, traction control was adopted, which prevents the wheels from slipping. After that, engine brake control was developed to mitigate intense engine braking when the vehicle is decelerated. Moreover, as shown in **Fig. 2**, shift control for shifting up or down without having to operate the clutch, wheelie control for keeping the front wheel from lifting during acceleration, and various other controls are used in almost every racing situation.

For racing, technologies are adopted to run faster and win. Now that engine and chassis performance is so sophisticated, technologies that reduce the rider's operational burden through rider-machine cooperation are required. These technologies are not only required for racing but also are a requirement that is consistent with Kawasaki's concepts, "Fun to ride" and "Ease of riding."

Based on control and other technologies cultivated through racing, motorcycle manufacturers are developing supersport models that are designed for circuit riding, which are then used as the base models for racing vehicles and symbolize their brands to show off their technologies.

With the evolution of microcomputers, which serve as control devices, gyro sensors using MEMS (Micro Electro Mechanical Systems) technology have now become cheap enough to be used in commercially available vehicles. In addition, with the progress of technological development, new control devices, such as electronic suspension, can be used in commercially available vehicles.

For the ZX-10R series supersport model, we are applying the control technologies we have cultivated through racing while using commercially available

technologies.

3 Concept of the ZX-10R series

The ZX-10R symbolizes Kawasaki's brand and is used as the base model for the World Superbike Championship, which is the biggest race for mass-production motorcycles. The ZX-10R's concept is "No. 1 circuit performance," and all the knowledge about engines, chassis, and control data obtained from racing have been fed back into the development of mass-production vehicles.

In racing and circuit riding you want controls that produce maximum performance while reducing the operational burden on the rider by having the machine cooperate with them. This applies to riding on public roads and not just extreme situations like in racing.

For racing vehicles, however, the rider that the machine needs to cooperate with and the riding conditions in racing can be limited but for mass-production or commercially available vehicles, there are still hurdles to overcome (e.g., rider's skills, riding conditions, devices (cost)).

As shown in **Fig. 3**, the ZX-10R series has been incorporating the control technologies available at the time of development ever since its first model.

The 2016-year model and subsequent ZX-10R models adopted wheelie control using an IMU (inertial measurement unit), and the 2017-year model and subsequent ZX-10R SE models adopted electronic control suspension. In this way, more and more advanced control technologies are becoming commercially available.

The following describes wheelie control, which is a typical example of control using IMU, and suspension control using electronic control suspension, which is a new

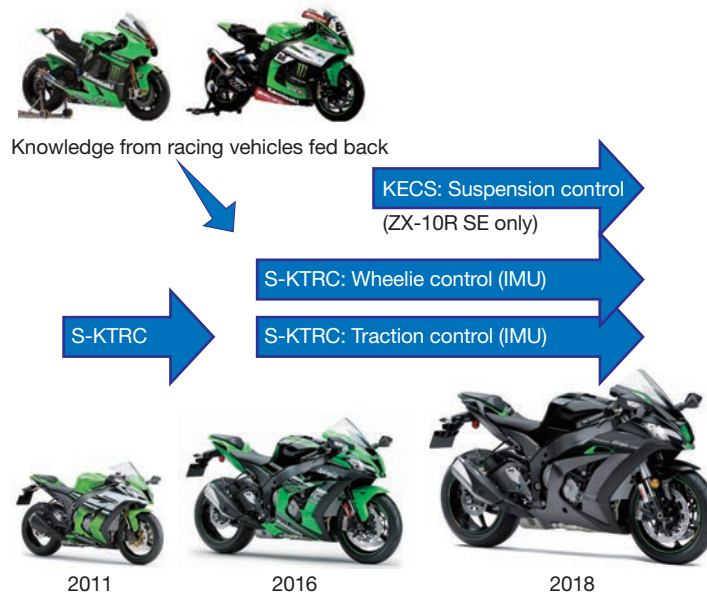


Fig. 3 Introduction of control technologies for ZX-10R

control device.

(1) Wheelie control

When accelerating, if the engine power is too high, it causes the front wheel to lift off the ground, resulting in a wheelie. When doing a wheelie, the vehicle cannot keep running fast but to run fast, ideally, the vehicle should accelerate with the front wheel nearly lifted, but precise throttle operation is required to achieve this.

Wheelie control is a function to monitor the vehicle posture and assists the rider's operation to reduce their operational burden and achieve maximum acceleration.

(2) Suspension control

Common suspensions have a fixed damping amount, and so cannot have different damping amounts for

different riding situations, such as accelerating and decelerating, turning, and changing direction.

The electronic control suspension shown in Fig. 4 has varying damping amounts, enabling optimal damping control according to the vehicle posture and situation.

4 Technological development

To achieve a high level of vehicle control, we are developing and verifying posture and behavior estimation technology, rider-machine cooperation in wheelie control, and electronic control suspension, which is a new device.

(1) Posture and behavior estimation technology

Vehicle behavior involves the rider's intention information in addition to the motorcycle condition



Fig. 4 Electronic control suspension (Kawasaki Electronic Control Suspension)

information, and behavior estimation is essential to achieving control for cooperation with the rider.

In the past, posture could not be estimated directly, so it was estimated indirectly based on the wheel speed and rider's throttle operation. In recent years, gyro sensors shown in **Fig. 5** have become available for mass-production vehicles. However, gyro sensor signals represent angular velocity, and so must be converted to posture or behavior.

Motorcycles have complicated movements, so with cheap gyro sensors, the posture cannot easily be estimated. For example, a turning movement involves a banking movement (lean) and a yawing movement as shown in **Fig. 6**. The banking posture is also a combination of multiple elements, such as the combined center of gravity of the vehicle and rider (balanced angle at a constant radius turn). For this reason, we are developing posture and behavior technology tailored for motorcycle movement characteristics.

In development of the logic, we link the simulation data

and actual data of vehicle movements to combine the theoretical and actual environments (measured vibration and variations).

(2) Rider-machine cooperation in wheelie control

Wheelie control is intended to control the engine torque according to the vehicle posture (wheelie), and Kawasaki is developing wheelie control taking "cooperation with the rider" into consideration.

(i) Degree of freedom of rider's operation

During a wheelie as well as during throttle operation, the rider is always paying attention to acceleration and deceleration. Therefore, we developed a control logic that allows the rider's intention to be reflected in the vehicle behavior in the allowable range of the degrees of freedom of the rider's operation as shown in **Fig. 7**, even during control intervention.

(ii) Increased adaptivity

What circumstances a wheelie occurs in depends on

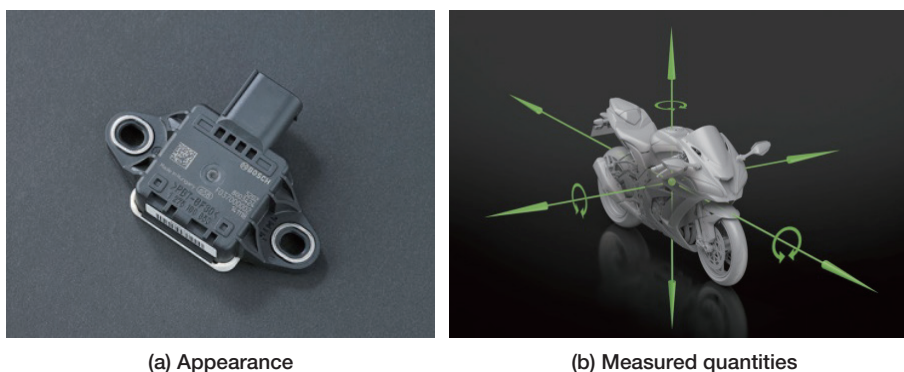


Fig. 5 Gyro sensor

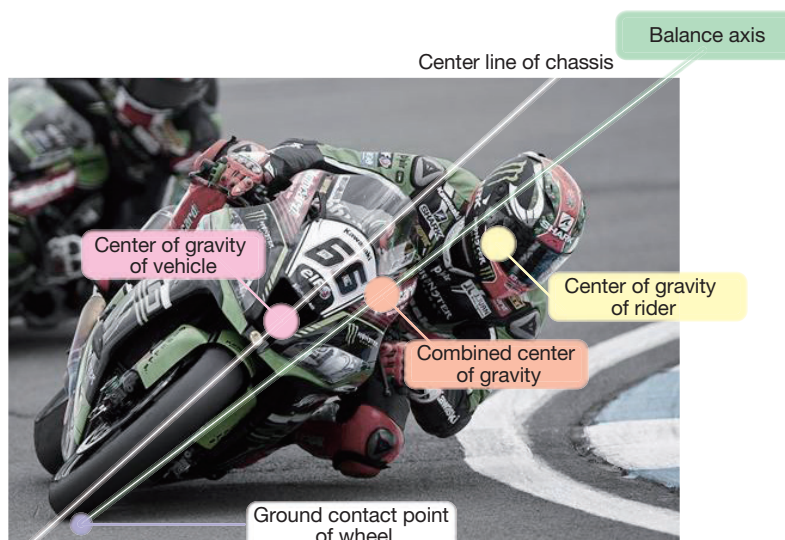


Fig. 6 Motorcycle posture while cornering (leaning)

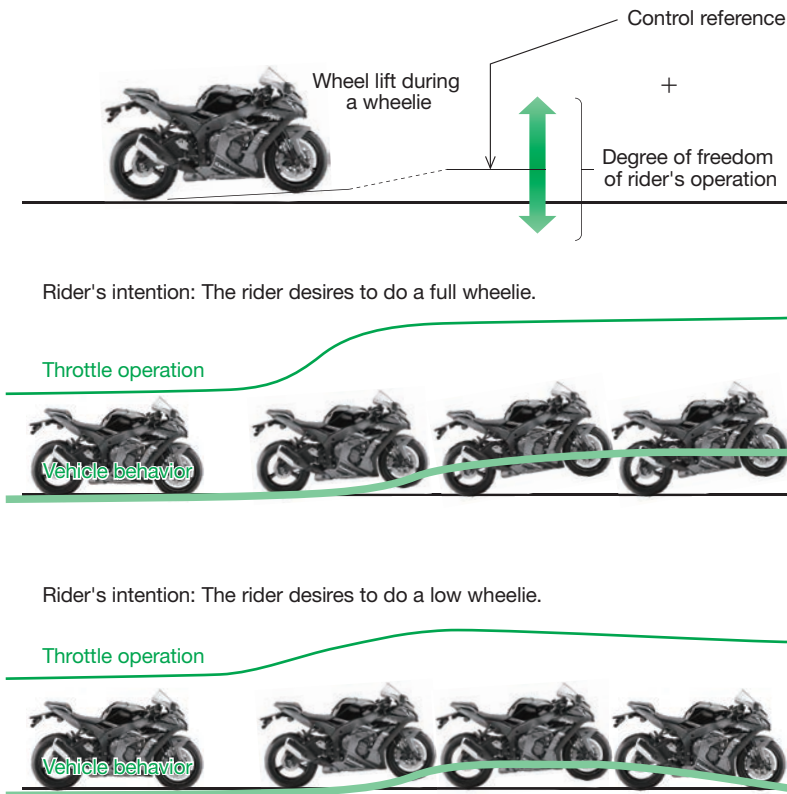


Fig. 7 Rider's degree of freedom during wheelie control

the weights of the vehicle and rider and road conditions. In addition, the required intensity of control intervention depends on the rider's skills and preferences.

For the ZX-10R, the intensity of control intervention can be adjusted in five levels, as shown in **Fig. 8**, making the vehicle adaptive to a wide range of situations. The intensity of the control intervention can easily be adjusted with a handlebar switch.

(3) Development and verification of suspension control

Suspension control is intended to control and optimize the damping amount based on the acceleration and deceleration information from the built-in stroke sensor and gyro sensor.

When developing a new control device, we usually checked and verified the control device by test-riding the vehicle. However, in order to address increased man-hours

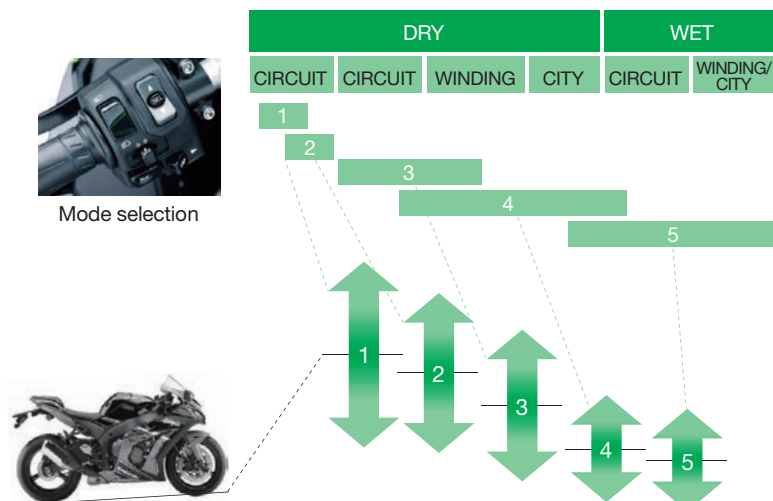


Fig. 8 Mode setting for wheelie control

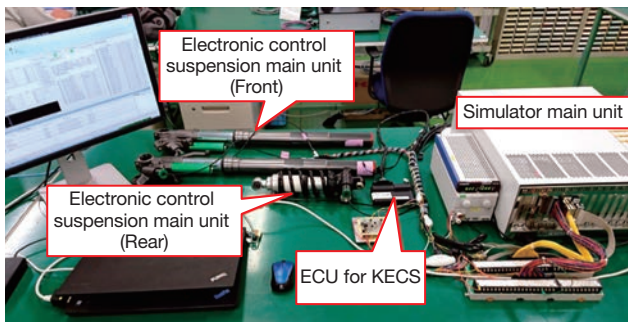


Fig. 9 Verification using HILS

due to increasingly complicated functions and ensure every necessary item is verified, we are using HILS (Hardware-In-the-Loop-Simulation) for verification in the development of suspension control.

In verification using HILS (Fig. 9), the actual ECU (Electronic Control Unit), sensors, actuators, and other components are used to conduct a real-time simulation, thereby making it possible to reduce the evaluation time of a test-ride and reproduce conditions that cannot be tested.

Conclusion

Because we fed the technologies that we cultivated through racing back into the ZX-10R, it has satisfactorily achieved a “Fun to Ride” and “Ease of Riding” and will evolve further to a higher level.

Various electronic controls and devices will be added not only to our supersport models, but our other motorcycles as well. Riding is a collaboration between the vehicle (machine) and rider and is based on a relationship of trust between them. This nature will not change even in the coming autonomous driving society. We will continue development to realize controls that can be relied on in a greater way by the rider and that enable rider-machine cooperation.

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