Construction of Riding Simulator for Two-wheeled Vehicle Handling

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Abstract – This paper describes the development and evaluation of a riding simulator (RS) for two-wheeled vehicles to analyze rider control behavior from the viewpoints of human factors and control engineering. In simulator development, sense of realism is divided into riding sensation and handling feeling. In addition, they are governed by the motion equation and the required pseudo-experience. In this study, we show the effectiveness of wide-angle change and stereoscopic vision in the front visual information. Also, we show that we could lower the degree of freedom of the system in normal travelling conditions. After that, we ensured the equation of motion could be stable at all speed ranges. Through these measures, we were able to reproduce the sense of a real vehicle's riding feeling and handling feeling. Since this simulator is able to generate a higher sense of presence than conventional RS, we were able to create a tool for analyzing the behavior of rider steering.

Key words: *Simulator, Two-Wheeled Vehicle, Human Factor, Stereoscopic, Control Engineering.*

Introduction

This paper describes the development and evaluation of a riding simulator (RS) for two-wheeled vehicles to analyze rider control behavior from the viewpoints of human factors and control engineering.
The number of two-wheeled vehicles continues to increase, especially in developing countries, for such reasons as price, operating costs, and user-friendliness. Therefore, research on two-wheeled vehicle handling is important for safety and usability. Since such vehicles tend to be small and light and have inherent balance requirements, the action of the rider’s body greatly influences the vehicle behavior. Therefore, we need to clarify two-wheeled vehicle behavior with human two-wheeled vehicle systems. In this field, however, theoretically analyzing the multi-control action of riders for two-wheeled vehicles is impossible because we need human-vehicle systems using experimental vehicles. In such field tests, riders are sometimes at risk. Attaching experimental instruments is also difficult because of the small carriers on the vehicles. In addition, at this stage, we cannot experimentally identify these inputs, especially the weighting factors of each input, their timing, and a reproducible method. One solution to these problems is to use a simulator of a two-wheeled vehicle for handling. In this study, we developed a riding simulator to investigate not only such human factors as mental workload and distraction but also a rider control algorithm. A system was constructed for RS and is shown in Figure 1.

Composition of simulator system

Motion Simulator Device

This riding simulator comprised of three degrees of freedom. They are roll-axis, pitch-axis, and steering-axis. At each of this axis, a servo motor is placed to operate and control the vehicle body movement. The angles, which are controlled by AC servo motors, are set to have movable range of ±15° for pitching angle, ±20° for rolling angle, and ±10° for steering angle.

Visual Simulation System Device

The front-view images are generated by a computer and then projected onto a screen installed in front of the system. 3D graphics development software called omega-space is used to generate these images.

Sound simulation system

The sound simulation system is meant to reproduce engine sound, which will act as engine sound feedback for the rider. The sound simulation system reproduces the different sound of engine by changing the frequency of the sampled sound relative to the revolution of engine.

Wind Simulator / Skin-sensation simulation system / Wind Generator Device

A system of blower is set in the under screen to give a virtual feelings of travelling wind to the rider. The amount of wind depends on the speed simulated at that moment. The blower emplacement is decided only after carefull consideration of the wind strength, range, and the rider's vision range. With the inclusion of this blower system the rider feels a more realistic riding experience.

Calculation and Control Devices

Motion information, rider's input and movement of the servo motor are all programmed to be controlled by computers.

Control System

A program called for Digital Signal Processor (DSP) was installed, in order to tune the model's parameters online in real time. This means when the simulator is running, the program allows the parameters to be altered and sees the result in real time.

Construction for front visual field screen images

RS needs to represent real vehicle feeling and handling feeling when we analyze a rider's handling action in it. Riders recognize and estimate a vehicle's feeling through kinesthetic sense, eyesight, hearing, and cutaneous feeling. Also, riders give control input to the simulator to achieve the desired vehicle motion. Thus, RS needs to increase information capacity and information quality for increased handling feeling. Also, we checked quasi-body sensory information for construction of front visual field screen images and a traction wind model. This paper describes construction for front visual field screen images as quasi-body sensory information. Previously, Morita considered rider's eyesight when steering a two-wheeled vehicle [TAK1]. This report showed that when handling a two-wheeled vehicle, a rider's gaze distribution is greater compared with a four-wheeled vehicle. Goshima noted that view-angle increase impacts the driver's sense of speed [You2]. In this study, experiments were performed to examine the needed view angle of a two-wheeled vehicle rider. As a result, we confirmed an increase in the feeling of speed from an increase in the view angle.

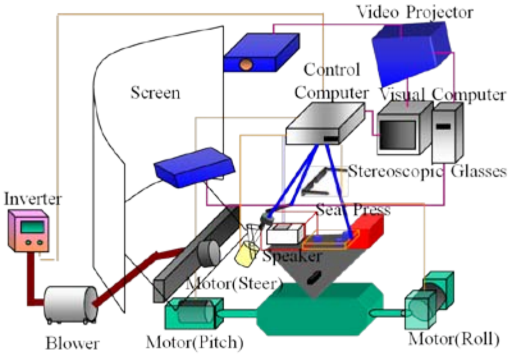

Fig.1 Outline of simulator system

Study on wide-angle changes

Experiments were performed to examine feeling of speed in the RS. The simulated course used a two-lane highway model. Figures 2 and 3 show the course that was used. The animation ran for 60 seconds as set by the experimenter, and the subject was informed of the time limit. As auditory information, we provided sounds sampled from a real vehicle engine. The experimental procedure included the following steps, and each experiment was carried out once. Subjects were three people with motorcycle licenses. We did informed-consent to them. There were four view angle conditions.

View angle condition 1: Horizontal view angle 100 [deg], Vertical view angle 45 [deg]

View angle condition 2: Horizontal view angle 100 [deg], Vertical view angle 87 [deg]

View angle condition 3: Horizontal view angle 207 [deg], Vertical view angle 45 [deg]

View angle condition 4: Horizontal view angle 207 [deg], Vertical view angle 87 [deg]

The five speed conditions were 45, 60, 65, 75, 85 [km / h].

Figure 4 shows the results of the experiment about wide-angle changes. In addition, Figure 5 shows the error rate about Figure 4 from the results of the experiment. It was confirmed that, with the increase of angle of view, sense of speed also increased. Table 1 shows the test of significant difference in experimental conditions. The results were obtained by the method of Dunnett. The'○' means that a significant difference could be confirmed. In addition, the '×' means that a significant difference could not be confirmed. The red color means the same condition on the vertical angle of view, and these show a significant difference on horizontal angle of view. The blue color means the same condition on the horizontal angle of view, and these show a significant difference on vertical angle of view. From these results, it is found that the under vertical view angle has greater influence than the horizontal view angle for feeling of speed.

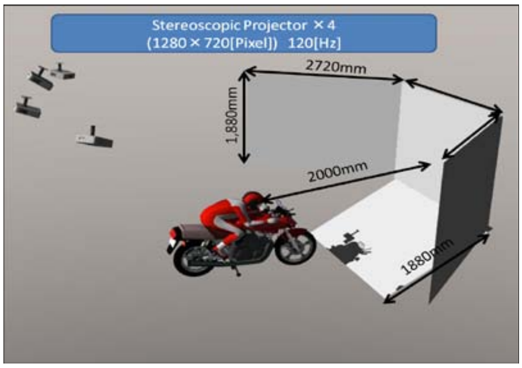

Fig. 2 Screen Image

Fig. 3 Scene of riding simulator

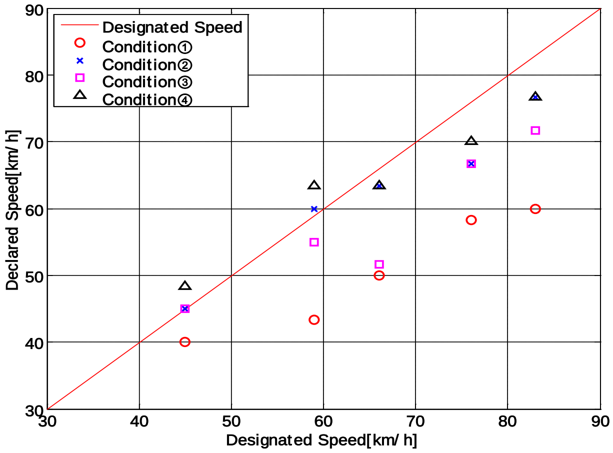

Fig. 4 Relationship between Designated Speed and Declared Speed

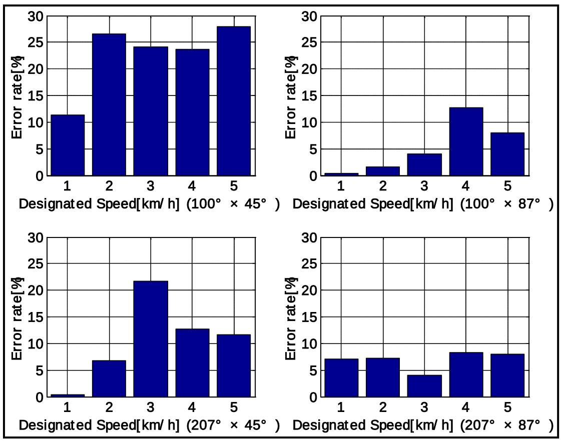

Fig. 5 Relationship between Designated Speed and Error rate

Table1 Test of significant difference

	Horizontal 100° × Vertical 45°	Horizontal 207° × Vertical 45°	Horizontal 100° × Vertical 87°	Horizontal 207° × Vertical 87°
Horizontal 100° × Vertical 45°		○	○	○
Horizontal 207° × Vertical 45°	○		×	○
Horizontal 100° × Vertical 87°	○	×		×
Horizontal 207° × Vertical 87°	○	○	×	

Study on impact of stereoscopic vision

Subsequently, we introduced stereoscopic vision into the image system to improve the feeling of distance. We used the "omega space" as a graphic tool [SOL3]. This tool can easily create stereoscopic vision through various methods. We used the LCD shutter method (refresh rate 120 Hz) to change the rider's perspective. A PC and an infrared emitter were connected to stereoscopic glasses and synchronized. Figure 6 shows the experimental environment. Experiments were performed to examine feeling of distance in the RS. The simulated course used a two-lane highway model. Figures 2 and 3 show the course that was used. First, they was enough practice running. Second, they watched running animation. And,We were asked to report to them at a specified distance. We will calculate the declared distance on the traveling time that has been reported. It then calculates the distance reported by subtracting the distance traveled from the first distance. We compare the declaration distance and the set distance, to makes an assessment of the sense of distance.

The experimental procedure included the following steps, and each experiment was carried out once.

Subjects were three people with motorcycle licenses. We did informed-consent to them. Evaluation was carried out on the Simulator (SSQ)[Ken4]. There were total of 18 conditions.

View Angle Condition：Horizontal view angle about 100 [deg], Vertical view angle about 87 [deg]

Velocity Condition: 60 km/h, 90 km/h,120 km/h

Visual condition: Planar vision or Stereoscopic vision

The experimental results were shown in Figures 7. Figure 8 shows the error rate on experimental results shown in figure 7. In addition we performed the test of significant difference. The one-sample t-test method was used as a significant difference test. Results of significance test, we confirmed the significant differences in the conditions which is the 20 meters. The stereoscopic vision method has binocular disparity and is effective primarily within a range of 20 metres. As a cause of distance feeling improvement, it is considered such as stereoscopic vision and a factor increase in the vertical viewing angle.

Next, we confirmed that visually-inducted motion sickness may occur with the increase of stereoscopic feeling. Figure 9 shows influence of the sickness. We confirmed that visually-inducted motion sickness may not occur by the increase of stereoscopic feeling.

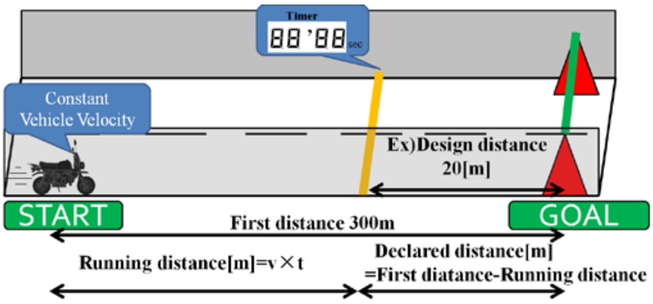

Fig. 6 Experimental Envernment

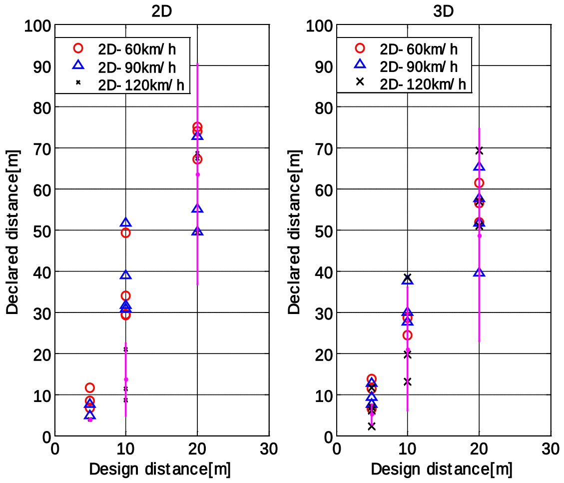

Fig. 7 Relationship between Designated Distance and Declared Distance

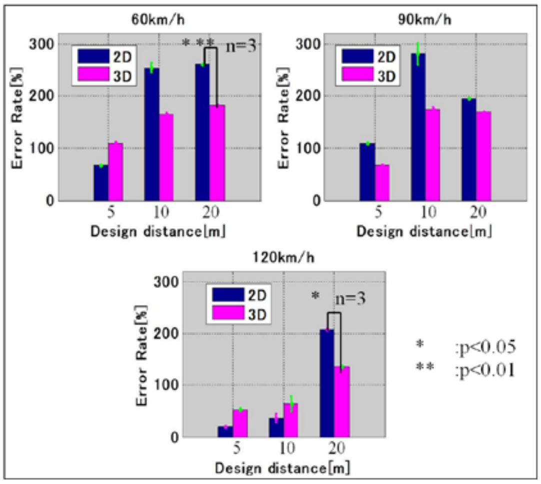

Fig. 8 Relationship between Designated Distance and Error Rate

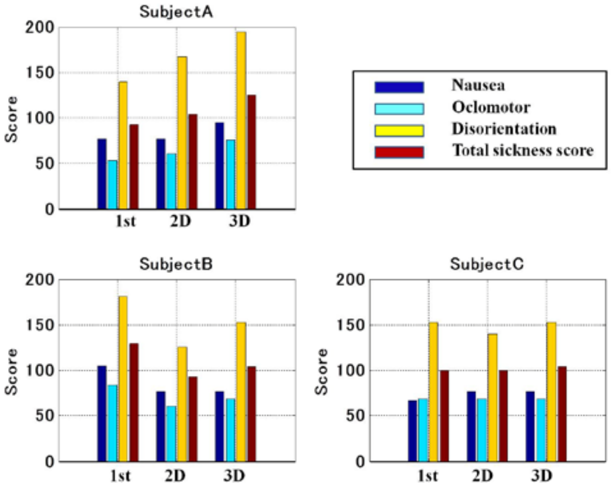

Fig. 9 SSQ Result (Stereoscopic condition influence)

System design

Determination of main control input

We have carried out an experiment to examine how the vehicle's main input control should be adopted to the RS. We conducted a double-lane change test and a pulse response test. We used the step reaction force, steering-torque and the seat-moment as control inputs of the riders. We used the yaw rate and roll rate as a response indicating the motion of the two-wheeled vehicles. From this result, yaw rate is seen to have the largest impact on the steering torque. In addition, the roll rate is seen to influence the change of attitude angle around the x-axis, and the steering torque is large. Thus, we found that steering torque is greatest in the control input of the rider for the motorcycle. As the second input, we changed the attitude angle around the x axis. Thus, we used these control inputs as the primary control input.[Oow5]

Determination of degree of freedom

We have measured the rotational center axis of motion for a real vehicle. Also, we investigated lowering the degree of freedom of the system.

We established the experimental vehicle accelerometer at 1.15 m and 1.45 m height. We conducted a slalom and acceleration-deceleration experiment. During the experiment, we measured the vehicle speed, acceleration and roll rate. The calculation results of the instantaneous center of rotation show the rotation center distance from the ground contact face. The negative value indicates the rotation center is located under the ground. These results indicate that we can lower the degree of freedom of the system in normal travelling conditions by setting it underground 0.5m, 0.9m from the instantaneous center of rotation about the roll axis and pitch axis. Thus, the degrees of freedom of the RS are three: roll axis, pitch axis, plus the handling axis that is the rider's interface during the simulation.

Lateral movement models

Stability limit of two-wheeled vehicle movement model

At present, most motion equations of a two-wheeled vehicle use models comprised of four degrees of freedom.
By using Sharp's analysis method, it is known that three-vibration mode controls most of the movement of a two-wheeled vehicle, and these vibration modes are called 'capsize', 'weave', and 'wobble'. Weave has a natural frequency of 1 - 4 Hz; while on the other hand Wobble has a high frequency of 6 - 10 Hz.
Therefore, it is impossible for the rider to control a two-wheeled vehicle when such high-frequency wobble vibrations occur, especially while the vehicle is traveling at high speed and tends to be unstable. [Sha6]
After comparison to other motion equations that have been published, it is known that under the occurrence of such high-frequency vibration, especially at a certain speed range, erratic and violent vibrations are most likely to occur. These motion equations can express the characteristic of a real vehicle relatively well, but not perfectly. Thus, by

using Eigenvalues and then correcting them, these motion equations can be used as lateral directional motion models for the simulator.

To simulate lateral movements and ultimately best express the characteristics of a two-wheeled vehicle, and also to construct models that could run stably at various speeds, in this research various motion equations' roots are revised to evaluate their characteristics.[Kag7]

Lateral motion model construction

The first step is construction of basic lateral movement motion equations.

These equations are created to find the 'transfer function'. Even though these equations do not represent the exact actual movement of the vehicle, these equations could give a rough image of what the motion would be like in a real situation. At this point, there is a need to consider other forces such as cornering force, camber thrust, self-aligning torque, and gyro-moment. In terms of degrees of freedom and simulation, other factors that need to be considered are steering-angle, roll-angle, yaw-rate, and four degrees of freedom lateral speed.

The next step would be deriving Eigenvalues from the motion equation from which an approximate value of (ω_n), damping ratio (ζ), time constant (T), and gain (K) can be found. These values are then rounded up.

To stabilize the system, the values of damping ratio (ζ) and time constant (T) are corrected.

Upon achieving that, each value is calculated using appropriate equations, and the roots of the equation are also corrected so that unstable values become stable. After these processes, a model of a two-wheeled vehicle that is stable at variable speeds and has all the basic characteristics of a two-wheeled vehicle are completed.

Using the coefficients derived from the above process, the transfer functions for the simulator are then determined. Factors such as steering angle (δ), simulator body rolling angle (Φ_w), computer graphic rolling angle (Φ_c), yaw rate (ω), and lateral velocity (V_y) are required to simulate a two-wheeled vehicle. Most of them are inputs by the rider. In addition to these, the vibration modes are then further improved. This is due to the fact that these factors would greatly affect the output variables (the angle of the handle: wobble ; rolling angle: weave and capsize ; yaw rate: weave ; and lateral speed: capsize). The transfer functions are shown as the following.

$$\frac{\delta}{T_h} = \frac{K_\delta}{s^2 + 2\zeta_1\omega_{n1}s + \omega_{n1}{}^2} \qquad (1)$$

$$\frac{\phi_w}{T_h} = \frac{K_{\phi_w}}{s^2 + 2\zeta_2\omega_{n2}s + \omega_{n2}{}^2} \qquad (2)$$

$$\frac{\phi_c}{T_h} = \frac{K_{\phi_c}}{T_1 s + 1} \qquad (3)$$

$$\frac{\omega}{T_h} = \frac{K_\omega}{s^2 + 2\zeta_2\omega_{n2}s + \omega_{n2}{}^2} \qquad (4)$$

$$\frac{V_y}{T_h} = \frac{K_{V_y}}{T_1 + 1} \qquad (5)$$

Thus, $K_\delta = \{-0.3 + 5.2\times10^{-2} \times log(V+1)\}^3 \times 1.82 + \{2.3\times10^{-2} - 3.9\times10^{-3} \times log(V+1)\}$ (6)

$$K_{\phi_w} = \{-7.5\times10^{-4}\} \qquad (7)$$

$$K_{\phi_c} = \{-1.2\times10^{-2}\} \qquad (8)$$

$$K_\omega = \{-3.0\times10^{-2} + 3.2\times10^{-3} \times log(V+0.1)\} \qquad (9)$$

$$K_{V_Y} = \{-2.25\times10^{-3} \times V - 4.0\times10^{-2}\} \qquad (10)$$

$$V = velocity \qquad (11)$$

Using the velocity derived from the calculations above, stability examinations of the lateral movement models could be performed. As mentioned, the models consist mainly with three main values such as 'capsize', 'weave' and 'wobble'. After some experiments, it is proven that the model is able to maintain stability at any speed.

By examining for certain changes in the load, changes in center of gravity of the simulator rider can be figured out. This can be achieved and calculated after placing a 'load-cell' in the inner compartment of the simulator. To calculate the input value of the simulator, there is a need to change input several variables' values into the equations. These variables consist of ‘seat-torque’ and addition of steering-torque ; also after consideration of first-order lag factors, the equation can be written in the following form:

$$Input = T_{st} \times \dot{M}_{st} + M_{st} + T_s \qquad (12)$$

In this equation, T_{st} is first order lag time constant, while M_{st} symbolizes seat-torque. After some subjective assessments, the time constants in the system are adjusted such that the rider is able to operate the simulator easily and experience more comfortable feeling. [Kag8]

Lateral Motion Simulation

At this part of the paper, there will be explanations on the lateral simulation model that involves factors such as calculations of yaw-angle, roll-angle, and the resultant yaw-motion.

First, yaw motion is simulated by using images and calculated by using the lateral motion model.

At the next step, the value of the yaw angle is then entered into the ‘visual computer’ for further processing.

Unlike the real two-wheeled vehicles, the riding simulator does not produce much centrifugal force, which could give an unrealistic feeling for the rider.

To overcome this problem, plenty of visual screen images and roll-motion are used to give the rider as realistic a feeling as possible. Moreover, to simulate a realistic capsize motion, light shaking of screens is used. The systems are further adjusted so that the rider would not feel any discomfort or experience any hazards by excessive screen vibrations. In regard to realistic motion for the simulator, only simulating capsize motion is not sufficient ; thus, by utilizing the simulator body vibration, weave motions were also generated. We using target roll angle and can be calculated the lateral movement model. Then the differences of the present roll-angle and the target roll-angle are again further processed by using PD control, in which the AC servo-motor output will be controlled by the PD control system.

Control System Design

A program called Digital Signal Processor (DSP) was installed to be able to monitor the model’s parameters and tune it when it is offline or online in real time. This means even when the simulator is running, the program allows the parameters to be altered and sees the result in real time. Additional benefits of this software are: (1) the riding simulator allows the system designer to quickly change and tune the initial design of the system by just changing parts of the system block diagram, and (2) the software allows changes even when the simulator is running, which allows instant feedback from the rider. Thus effective parameter tuning could be achieved in shorter time. [Kus9]

Evaluation of simulator system

This simulator can produce a higher sense of realism than conventional RS, and we were able to create a tool for the analysis of rider steering action. This simulator is very effective in the analysis of control behavior in a certain limited range, but all speed ranges are not reliable. In addition, this simulator can represent different characteristics to implement two different types of motorcycle chassis. In this paper, by using the RS developed by experiment and analysis, we constructed a two-wheeled vehicle simulator that humans can control. Thus, this simulator can analyze steering action in a limited range. In addition to the steering action analysis, it would be possible for use in human-machine interface (HMI) and the development of an advanced safety vehicle (ASV). In the future, we will describe applications of the RS.

Conclusion

In this paper, we developed a motorcycle simulator that humans can control by experiment and analysis. In a simulator, realism is particularly important. In simulator development, the sense of realism is divided into riding sensation and handling feeling. In addition, they are governed by the motion equation and the require pseudo-experience. The results are summarized as follows.

1) As the improvement in a sense of speed, it is important to adopt the wide viewing angle, especially around a front wheel.

2) We introduced stereoscopic vision to improve the sense of distance. From this experimental condition, stereoscopic vision is able to verify the improved distance feeling. Therefore, it is concluded that the stereoscopic vision is effect to improve the sense of distance.
3) Steering torque is the biggest input to the motorcycle to control by the rider. As the second input, we need to adopt the attitude angle around the x axis.
4) We performed the experiments and analysis on degrees of freedom. Analysis results indicate that we can lower the degree of freedom of the system in normal travelling conditions by setting it underground 0.5 m, 0.9 m from the instantaneous center of rotation about the roll axis, pitch axis. Thus, the degrees of freedom of the RS are degrees of freedoms of three: the roll axis, pitch axis, plus the steering axis that is the rider's interface during the simulation.
5) We examined the lateral model in the two-wheeled vehicle's equation of motion. We derived Eigenvalues from the motion equation from which an approximate value of (ωn), damping ratio (ζ), time constant (T), and gain (K) can be found. To stabilize the system, the values of damping ratio (ζ) and time constant (T) are corrected. Using the coefficients derived from the above process, the transfer functions for the simulator are then determined. In addition to these, the vibration modes are then further improved. This is because these factors greatly affect the output variables (the angle of the handle: wobble; rolling angle: weave and capsize; yaw rate: weave; and lateral speed: capsize). After some experiments, the ability to maintain stability at any speed has been demonstrated.
6) By examining for changes in the load, changes in the center of gravity of the simulator rider can be figured out. This can be achieved and calculated after placing a ‘load-cell’ in the inner compartment of the simulator. Furthermore, we add that sheet-moment as the handling-torque moment was measured from the load cell, and was treated as the first-order lag element.
7) We constructed a Control System using the Digital Signal Conditioner (DSP) to improve steering feeling. As a result, tuning in real time becomes possible, and efficient design has become possible to detail. Thus, the discomfort of the rider can be lessened.

Through these measures, we were able to reproduce the sense of a real vehicle's riding feeling and handling feeling. This simulator generates a higher sense of presence than conventional RS, and we were able to create a tool for analyzing the behavior of the rider steering. In the future, we will use an available advanced safety vehicle (ASV) and human-machine interface (HMI) in addition to the analysis of steering behavior, and describe the applications of the RS.

References

[Tak1] TAKANOBU.M. “ON VISUAL INFORMATION SEEKING OF MOTERCYCLISTS”. Department of Human Science Osaka University Bulletin, 4, p.239-265, 1978

[You2] Youichi GOSIMA, et al, “Improvement of Driver’s Feeling to a Driving Simulator”. Japan Society of Mechanical Engineers, No.03-8, 8th ‘’Motion and Vibration Control’’, (in Japanese with English summary).

[SOL3] SOLIDRAY CO., LTD.’’**http://www.solidray.co.jp/product/omega/index.html’’ .**

[Ken4] Kennedy, N.E., Lane, K.S., Berbaum, K.S., and Lilienthal, M.G. 1993 Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The International Journal of Aviation Phychology,3 ,203-220.

[Kat5] Katuyuki OWADA, et al, “A Study of a Rider Model for Two Wheeled Vehicle Handling”. JSAE,No.942,pp.41-44 (1994).

[Sha6] R.S. Sharp; THE STABILITY AND CONTROL OF MOTERCYCLE, JOURNAL MECHANICAL ENGINEERING SCIENCE, pp.316-329,1971,Vol.13 No.5

[Kag7] Kageyama, et al, Development of riding simulator for two wheeled vehicle, Proceeding of 9th Trans-Log Meeting of JSME, No.00-37, 2000(in Japanese with English summary).

[Kag8] Kageyama, et al, Development of riding simulator for two-wheeled vehicle, Trans, JSAE 23 , 2002.

[Kus9] Kusakari, et al, Fundamental Study on HMI for Advanced Safety Vehicle on Indication Method of Information for Active Safety of Two-wheeled Vehicle, Trans. JSAE 38 (4) , 2007