

Motorcycle Dynamic Simulation Model Incorporating Actual Rider Behavior Data

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ABSTRACT

For motorcycle dynamic simulation, the rider had previously been defined as a mass that is fixed on the motorcycle; therefore, examining and applying rider behavior to dynamic simulation models have been long-standing issues. This research established a dynamic model that simulates running on a winding road course while incorporating rider behavior. Rider behavior in actual running tests was digitalized using an image-processing-type motion capture system. By applying the digitalized behavior data to the motorcycle simulation model, the actual rider behavior was accurately modeled. Actual running paths for the simulation were measured using a Global Positioning System. Calculation accuracy of the rider model weight shift during acceleration and deceleration on the winding road course was enhanced by applying the acquired rider behavior data and the motorcycle dynamic simulation model which incorporates the multi-degree-of-freedom rider model, into the multi-body dynamics analysis software.

1. Introduction

Motorcycle running simulation using multi-body dynamics analysis software, such as straight forward stability and steady state circular simulations, have a higher correlation with actual running tests, and are widely used to develop products and to perform academic research⁽¹⁾⁻⁽³⁾. However, the rider model in these simulations is defined as a fixed mass or a simple rider model with one or two degrees of freedom. It was a challenge to apply this simple rider model to research on steering characteristics accompanying rider behavior. This research focused targets on examining rider behavior, including active weight shifting and steering maneuverability while accelerating and decelerating on a winding course, and also on realizing closed course running simulation for the development of super-sport type motorcycles. The first step was to construct measurement technology and simulation technology accurately reproducing rider behavior and motorcycle trajectory.

In order to reproduce actual rider behavior, it was necessary to establish a method of measuring the behavior of the various parts of the rider's body, such as the hips and shoulders, and to incorporate a body simulation model

that could reproduce this behavior more realistically into the motorcycle simulation model. In the past, the target running line was defined by a simple straight line or circle, but now it has become necessary to prepare one system for measuring actual motorcycle trajectory to perform calculations for winding courses. This paper describes a method of measuring rider behavior and motorcycle trajectory, and reports results when applying the rider's behavior data and actual trajectory data to a simulation, together in an actual case study.

2. Measurement Technology and Simulation Method

Figure 1 shows the flow from measurement to calculation. First, rider behavior, motorcycle trajectory, and motorcycle behavior when running on a winding course are measured, and the obtained data is incorporated into a simulation model in order to perform calculations for winding course running tests, which include acceleration and deceleration. Details are set out below.

2.1. Method of Measuring Rider Behavior

In the research carried out by Katayama and others, a rider behavior measurement system was devised that uses

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a link mechanism to couple the rider to the motorcycle⁽⁴⁾. Also, in recent years, progress has been made in body behavior measurements using motion capture technology, which is utilized in the fields of sports medicine and computer animation. A system that could accurately measure rider behavior during motorcycle riding was examined based on the prerequisites that the steering behavior of the rider be unrestricted, and that the system be small enough not to affect the motorcycle behavior. As a result, for this research, the decision was to use a motion capture method that obtains 3-dimensional coordinate data of the rider's body from video using one CCD camera⁽⁵⁾.⁽⁶⁾ To acquire video images that have little distortion and a shooting range that can cover the rider's range of motion, the camera lens and its position were studied (Fig. 2).

The basic theory of video processing is as follows. Figure 3 shows an example of the measured results obtained when a rider wearing a vest with a checkerboard pattern leans forward and moves laterally while straddling a stationary motorcycle. The yellow lines in the figure indicate the contours of the lattice pattern (hereafter called "pattern") on the back of the rider in the normal position. When the rider leans forward from the normal position,

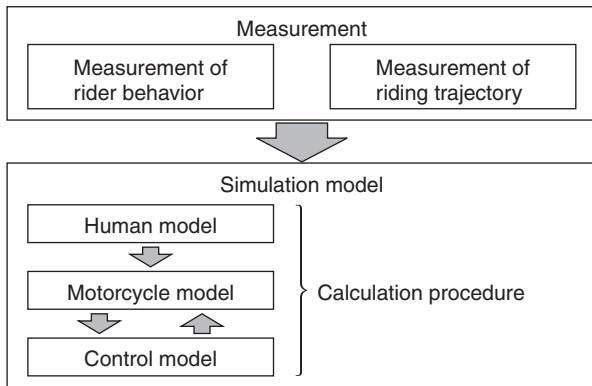


Fig. 1 Process flow from measurement to simulation



Fig. 2 CCD camera position

the pattern on the back of the rider in the moving images changes gradually from that in Fig. 3 (a) to Fig. 3 (b). Looking at the change in the pattern on the rider's back shown in Fig. 3 (b), it can be seen that the rider leans forward progressively, while moving his back forward. Figure 3 (c) shows the rider's position resulting from the normal position to the left by lateral movement. Looking at the change in the pattern in this case, it can be seen that as the rider moves laterally, his left shoulder moves forward. Motion capture software (hereafter called "capture software") traces and analyzes changes in the pattern on the moving images, enabling the positional change (behavior) in the human body to be extracted. It was confirmed that the accuracy of this software was within 10 mm, with respect to both longitudinal and lateral motion of the rider.

The method of acquiring rider positional behavior from the video information together with an example of implementation (Fig. 4) is described below. It is assumed that the images are processed in video units cut to an arbitrary length. First, the basic dimensions, such as the height, shoulder width, arm length, and the like (hereafter called "each part of the body") of a simplified body model on the capture software expressed using a yellow wire model, are matched to the actual dimensions of the rider. Next, the position and posture are adjusted (hereafter called "associated") so that each part of the body of the rider in the video coincides with each part of the body of the simplified body model in the first frame of the video unit. The capture software calculates the positional change of the simplified body model so that it matches the change in the video pattern, and continuously traces and extracts the position and posture of each part of the body. To minimize the cumulative error generated inside the capture

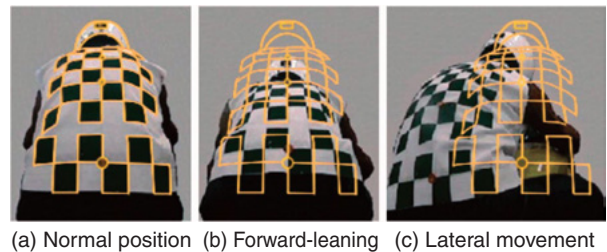


Fig. 3 Example of rider position while riding

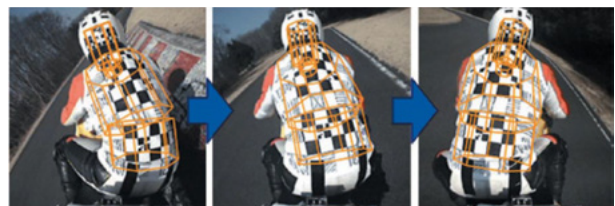


Fig. 4 Consecutive movement of rider

software, the rider in the video and the simplified body model are associated with each other even at the final frame of the video unit, and the positional change is calculated going in the reverse direction from the final frame to the first frame. The acquired data is used as behavior data for the human model that has been newly incorporated into the motorcycle simulation model.

2.2. Motorcycle Trajectory Measurement Method

For measurement of the winding course motorcycle trajectory, sufficient accuracy to obtain the difference between each rider was necessary. The inertial navigation system, remainder mark device, and the like, have been known for many years as methods of obtaining motorcycle trajectory. However, these days, a Global Positioning System (hereafter called "GPS") is generally used for vehicle speed and position, and has come into increasing use on motorcycles due to its compactness and higher performance. GPS was focused on for this research and the measurement of the motorcycle trajectory using GPS is described below. The large banking angle and the rolling and pitching behavior, which are characteristics of a motorcycle, often produce an angular change in the GPS antenna, which degrades reception, thus interfering with stable measurement⁽⁷⁾. For this reason, the position of the GPS antenna was determined not to shut off the radio waves from the GPS satellite, and one GPS that was suitable for mounting on the motorcycle was selected from the result of comparative testing of the motorcycle trajectories with several types of GPS systems. The information concerning the latitude, longitude, and the like, of the measured trajectory was coordinate-converted into ground position information. Also, because a discrepancy had occurred between the antenna mounting position and tire ground contact position, calculation using the measured data from motorcycle-mounted roll angle speed sensor was performed to locate the tire to ground contact point.

2.3. Simulation Model

The body model and body control model used in this research are described below.

2.3.1. Human body model

In this research, a body model that could accurately reproduce rider behavior on a computer was acquired. The body model was divided into 19 parts, and the mass and moment of inertia were defined for each of these parts. Here, the data was acquired by referring to the body database GeBOD⁽⁸⁾. In addition, because the load reaction and the like can be calculated, at each joint, it is considered that in the future this body model can be applied to technology for predicting rider fatigue, riding comfort, and the like. By inputting basic information, such as the rider's height and weight, a body model is made from a database that includes the actual mass, moment of inertia, and the like, in each part of the body. Next, by inputting the angle and coordinate position information of each part of the body, the body position on the motorcycle simulation model can be determined. The body model is connected to the motorcycle model at a total of five points, right and left handles, hips, and right and left steps. The rider behavior is treated as the shift at each part of the body along with the passage of time.

2.3.2. Motorcycle model

The motorcycle model is shown in Fig. 5. It consists of a total of nine elements, namely the sprung steering components, the unsprung steering components, the front tire, the rear body which includes the engine, the rider,

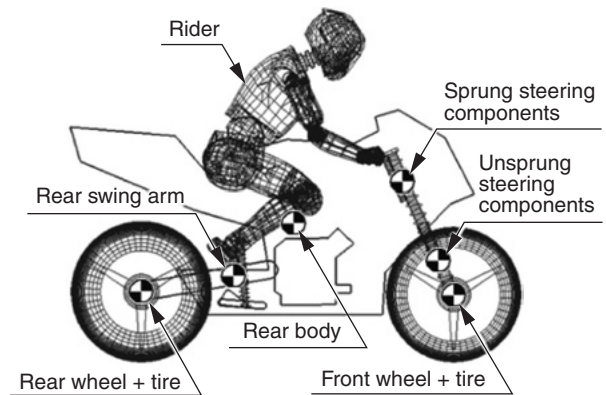


Fig. 5 Motorcycle simulation model

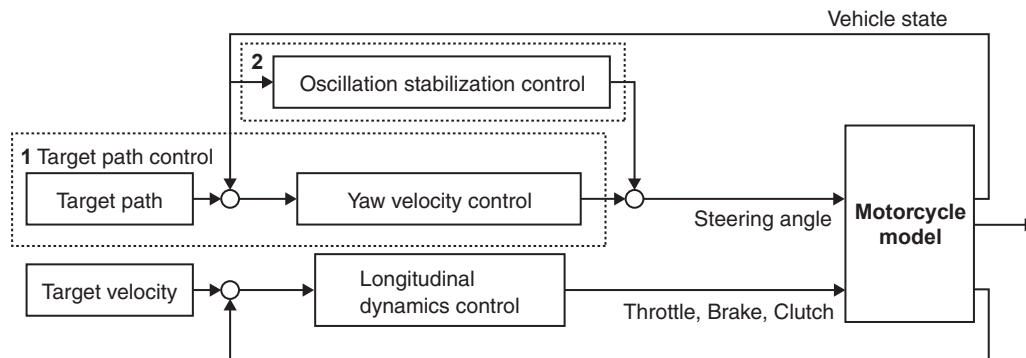


Fig. 6 Control model for motorcycle simulation model

the rear suspension and the link mechanism, the swing arm, and the rear tire. The frame body, front fork, and swing arm are treated as rigid bodies. The Magic Formula tire model is used as the tire model⁽⁹⁾.

2.3.3. Control model

The control model is divided into control in the lateral direction and control in the longitudinal direction. The control model used in this simulation model is shown in Fig. 6. The lateral direction control model, which controls the steering angle of the motorcycle model, consists of two controls: one control which follows the target running line that satisfies the balance in the rolling direction (1 of Fig. 6), and the other control for reducing vibration of weave and wobble (2 of Fig. 6). The algorithm of the control that follows the target running line uses optimization calculations to obtain the target yaw angular velocity that results in as smooth running as possible, from the deviation and curvature between the current motorcycle condition amount and target running line that is seen from the first prediction position after Δt seconds running. A feedback control model, which controls the steering angle according to the difference between the target yaw angular velocity and current yaw angular velocity, was achieved⁽¹⁰⁾.

The longitudinal direction control model was designed to control the throttle opening according to the engine speed with respect to the target motorcycle speed, and to select the appropriate gear and operate the clutch. The model was also designed to change the front and rear brake force distribution.

2.3.4. Calculation procedure

- (1) The rider behavior data is converted into the shift from the reference point on the motorcycle simulation model and created as a dedicated format.
- (2) The actual motorcycle trajectory data is created as a dedicated format converted into the tire ground contact

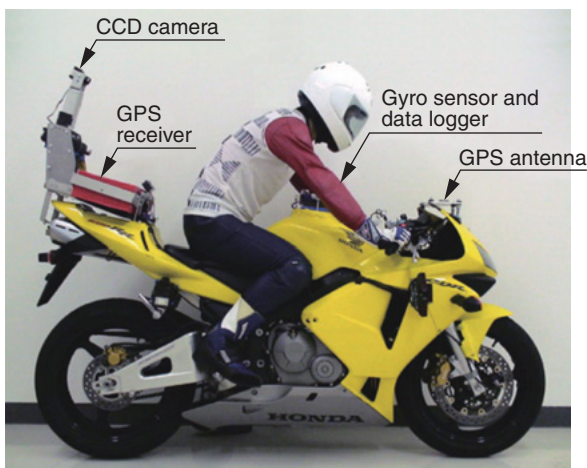


Fig. 7 Test motorcycle and location of measuring instruments

- point, and represents the target course.
- (3) The motorcycle speed data and motion distance data are created as a dedicated format, and represent the target speed.

These three files are read into the multi-body dynamics analysis software, and calculation is performed.

3. Running Measurement, Including Rider Behavior, and Measurement Results

3.1. Measurement Motorcycle

Figure 7 shows the measurement motorcycle. The motorcycle has a displacement of 599 cm³, mass of 209.3 kg, and a wheel base of 1.39 m. The measuring instruments were a motorcycle angular velocity sensor and data logger mounted on the fuel tank, a GPS mounted on the rear seat, and a GPS antenna located above the front meter. The CCD camera for recording rider behavior was fixed to the rear. The longitudinal and lateral acceleration, yaw and roll angular velocity, steering torque, steering angle, right and left step load, and front and rear suspension stroke were measured as the motorcycle behavior data. Also, to synchronize the rider behavior video and motorcycle behavior data, a photoelectric switch was mounted on the motorcycle and which reacts with a reflector plate, located along the side of the running course. One of the signals output from the switch was recorded on the video-side using an LED light emitting circuit, and the other signal was recorded to the logger for measuring data. The GPS was used to specify the position of the reflector plate, thus facilitating synchronization of the rider behavior, motorcycle behavior, and trajectory, as well as their application to simulation.

3.2. Results of Measuring Rider Behavior

Seven in-house test riders were asked to ride freely along the winding course, and measurements were

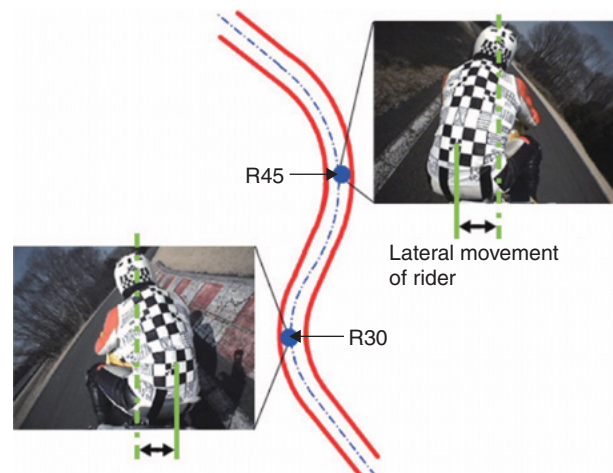


Fig. 8 Rider behavior on right-and-left turn

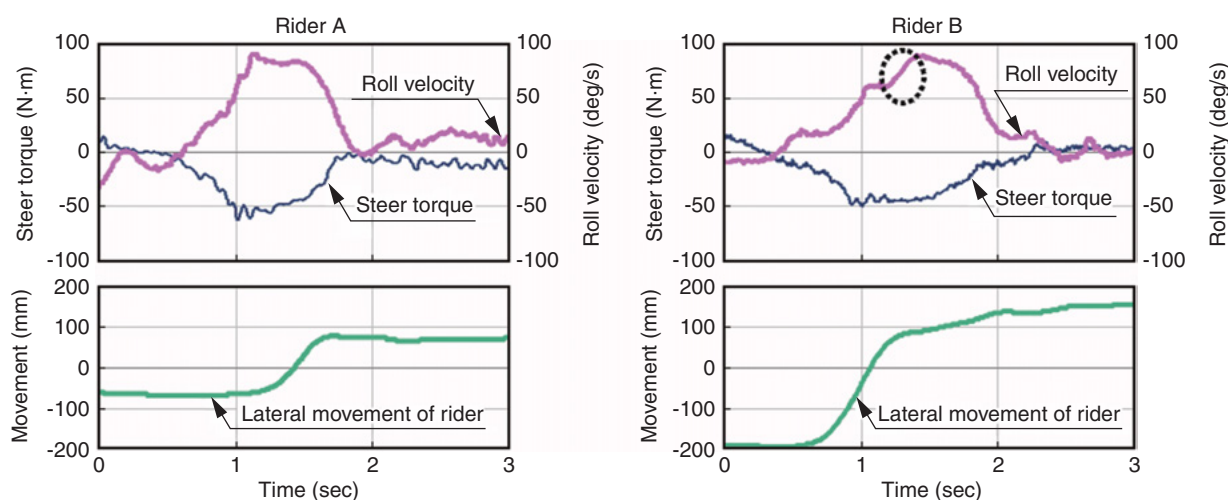


Fig. 9 Results of rider behavior

performed for each rider. As a result, the differences of the steering maneuverability and motion of the rider's body, the motorcycle behavior and trajectory, and the like, among different riders, were obtained. As an example, Fig. 9 shows the steering torque, roll angular velocity, and lateral motion of the hips, for two riders concerning which differences were found when the riders were making right and left turns (Fig. 8). For example, the lateral motion of the hips of rider A was small, and correlation was found between the steering torque and time series waveform of the roll angular velocity. In other words, in the case of rider A, the rider imparts roller behavior to the motorcycle by steering torque. The timing of the motion of rider B's hips is earlier than that of rider A, and the motion is also larger. Also, looking at the relationship between the motion of the rider's hips and the roll angular velocity, the roller angular velocity increases after the motion of the rider's hips is completed (indicated by the dotted line in Fig. 9). Because there is no notable change in the steering torque at this time, it is thought that this increase in the roller angular velocity is the roll behavior due to the shift of the rider's weight. Consequently, rider B features the use of a steering torque and weight shift to impart roll behavior. The measurement technology used in this research enabled the rider behavior

accompanying the weight shift to be converted into data, thus enabling the features of each rider to be clarified. In this measurement example, the measurement items were classified into rider behavior, handle operation, and motorcycle trajectory. From the seven riders, rider B was identified as a rider who performs standard operations. The rider behavior data obtained by measurement is applied to the motorcycle simulation model, and is used in calculations incorporating the features of the rider.

3.3. Results of Measuring the Motorcycle Trajectory

Figure 10 shows measurement results for the trajectory obtained from the GPS used in this research. A 30 m radius circle and straight lines indicating the approach and escape directions were drawn on the course. The riders ran a number of times trying to follow these lines. As a result, the dispersion of the trajectory was approximately ± 1 m in the width direction of the photoelectric switch reflector plate, as indicated in the figure. In the case of the winding course, on the other hand, generally satisfactory results were obtained, but on some corners an error of several meters occurred. It is thought that this was due to the GPS not being able to exhibit its normal performance because the GPS antenna is tilted. In the future, it will be necessary to focus attention on technology used to correct the measurement data and enhance accuracy of the GPS system.

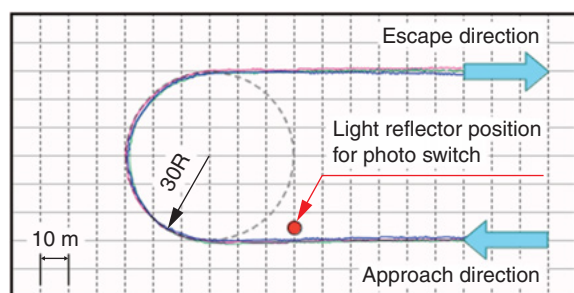


Fig. 10 Measurement of riding trajectory

4. Applied Case

As an applied case, Fig. 11 shows a simulation of running on the Twin Ring Motegi North Short Course of Mobilityland Corporation. The course has a total length of 982 m⁽¹¹⁾. Figure 12 shows the data obtained from an actual running test and the calculated results. The red line represents the test values and the blue line represents the calculated values. From top to bottom, the figure shows the motorcycle speed, roll angular velocity, and yaw

angular velocity. Apart from some exceptions, the calculated values basically agree with the test data, and it was confirmed that the rider behavior acquisition and trajectory at the tire ground contact point, which were constructed in this research, contributed to the increased degree of repeatability of the actual running test. It is considered that the difference between the test data and calculated values obtained at the low-speed corner indicated in the dotted line border in Fig. 12 is due to the fact that GPS motorcycle trajectory data was more inside than the actual trajectory.

Next, Fig. 13 shows an example of a comparative calculation between the cases with rider behavior and without it. There is a difference between the scale of the steering torque and the roll angle at a continuous corner which results in large rider behavior (Fig. 14). When

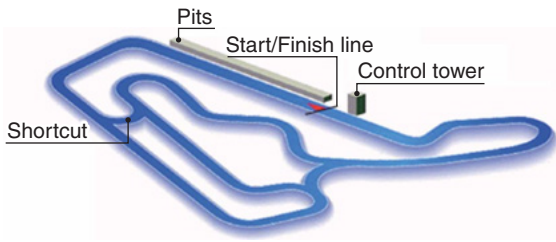


Fig. 11 Twin Ring MOTEGI (North short course)

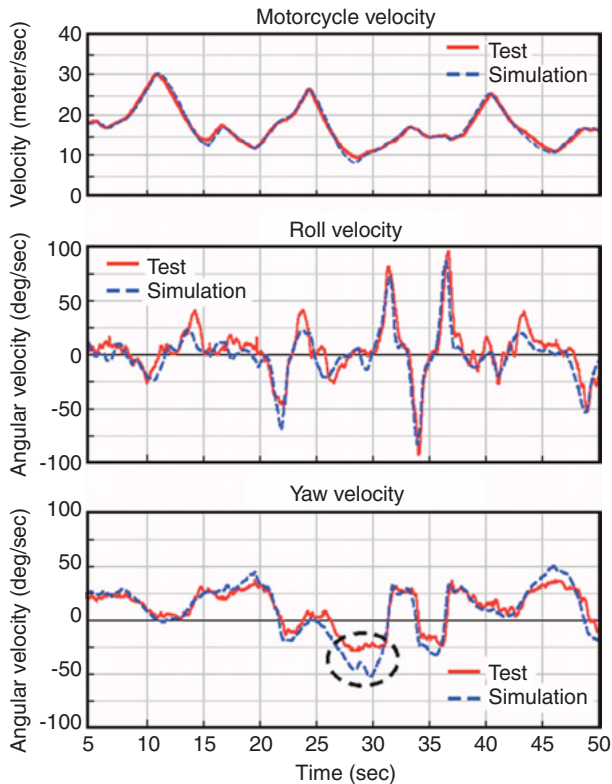


Fig. 12 Comparison between simulation results and test data

there is no rider behavior, the roll angle at the corner becomes larger, and there is a tendency to overshoot. By applying the rider behavior to the motorcycle simulation model, it was confirmed that the roll angle of the motorcycle had been reduced.

From the foregoing, it was found that by introducing a rider model with many degrees of freedom to the conventional motorcycle running simulation model, and by assigning the rider behavior and motorcycle trajectory obtained from actual running as data, composite course running, which included acceleration and deceleration, was realized.

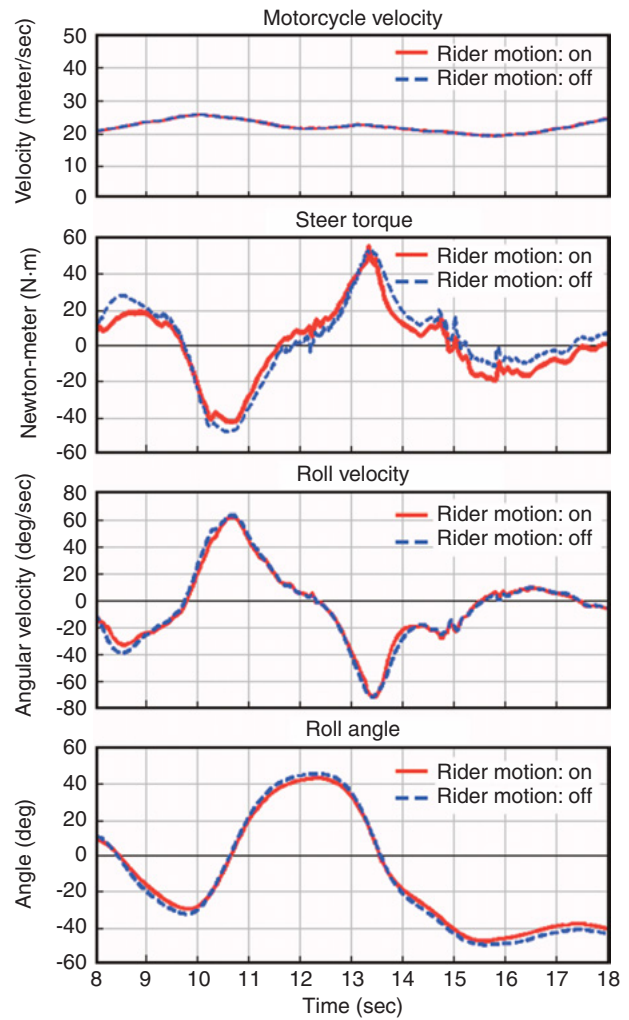


Fig. 13 Simulation results with or without rider movements

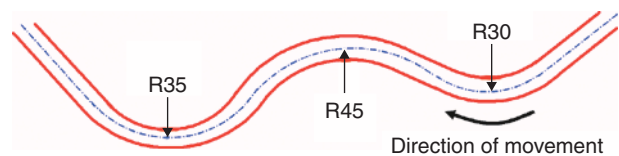


Fig. 14 Test course

5. Conclusion

- (1) By utilizing a motion capture system, a measurement method that acquired rider behavior during actual running as 3-dimensional data was established.
- (2) It was found that the actual motorcycle trajectory for a motorcycle was calculated by converting GPS observation data into the tire ground contact point using roll angular velocity information.
- (3) It was found that the motorcycle running simulation of a composite course, which included acceleration and deceleration (circuit, for example), was realized by accurately reproducing the rider behavior during actual running and assigning the actual trajectory as the target course.

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