ABSTRACT

In 1996, the Japanese Road Traffic Act has been changed and driving schools have been obliged to use riding simulators in lessons. For this purpose, three types of riding simulators have been developed and authorized. They were aimed for traffic safety lessons and trial riding experience. However their maneuverability and stability are different from those of real motorcycles.

On the other hand, a few riding simulators have been developed to study on the maneuverability and stability of rider-motorcycle systems. The four degrees of freedom motorcycle-model, which was proposed theoretically, has been installed to them but they could not realize the feeling of the real motorcycle and they were hard to be ridden.

So we carefully have investigated the former theories, and reconsider how to reproduce the real motorcycle feeling. From these investigations, we propose a new type of motorcycle simulator.

1. INTRODUCTION

The basic performances of a motorcycle is "run", "turn" and "stop" as same as a four-wheel vehicles, namely acceleration, maneuverability, stability and breaking. However the different point from four-wheel vehicles is that the roll angle of the motorcycle is not restricted. Then a motorcycle always has the danger of falling down, but a rider makes a motorcycle stable with their proper controls, because of its easy handling, a motorcycle is familiar to many people.

The dynamics of a motorcycle is quite confusing considering as a man-machine system, and the evaluation method of the maneuverability and stability of it has not developed yet. The influences of the rider's behavior are quite large and detail analyses has not made yet. It has been generally said that the analyses by using a simulator are efficient to understand a man-machine system.

In the past, a few motorcycle simulators have been developed for this purpose but none of them has succeeded to reproduce the details of the real feelings of a motorcycle.

Here, we investigate the former reports on motorcycle simulators developed in Japan. Based on the investigation, we are now developing a new motorcycle simulator and we would like to make an interim report of that.

2. MOTORCYCLE SIMULATORS DEVELOPED IN JAPAN

In 1988, HONDA Co. Ltd. [1] started to develop a series of motorcycle simulators. Their purpose was to find out the possibilities of

(1) Research on maneuverability and stability by simulators
(2) Training materials for safety riding education.

To express the motion of 4 degrees of freedom (lateral, yaw, roll, pitch) and the motion around the steering axis of a motorcycle, the simulator had 7 movable axes.
including the steering axis. To reproduce the longitudinal acceleration faithfully it has a swing mechanism as shown in Fig.1. The linear motion equation of four degrees of freedom proposed by R. S. Sharp [2] was employed combining a nonlinear longitudinal acceleration term to reproduce the dynamics faithfully.

But they had several problems as follows;

1. In extreme slow speeds, the riders could not ride on the simulator.
2. In the cornering situation, the riders could not drive along the corner. Because centrifugal force is slightly different from the real motorcycle.
3. In the entrance of corner, the riders have a tendency to steer at first to the same direction of the corner. The inverse steerage did not appear on the simulator.

In 1996, for the change of the Road Traffic Act, they put a mass-produced model on the market. It has been simplified to have only 3 movable axes (roll, pitch direction and the steering axis). Because this simulator is used for safety riding lessons, easy riding and good virtual reality are much more important than the real dynamics based on physical laws. This simulator is reported to reproduce the following feelings by the controlled roll, pitch and steering motions driven by 3 servomotors.

1. The bank feeling and stability are represented by controlled roll and steering movements. The longitudinal acceleration feeling also by controlled pitch movement.
2. Good riding feel is produced by making the height of the roll rotation center 250mm and the pitch rotation center 400mm.
3. Sudden braking actions are represented by controlling the braking force in proportion to the input from the rider.

3. DRIVING MODEL OF THE RIDER

When we discuss about the maneuverability and stability of a motorcycle, it is important to know the control behavior of the rider. Several dynamic models of motorcycle-rider systems are proposed by theoretical analyses and their validity has been proved by computer simulations and real motorcycle experiments. Here we take a general view of Katayama’s model [3] of rider’s action as shown in Fig.3.

The Sharp’s linear 4 DOF model as motorcycle dynamic equations are used and considers the rider’s upper and lower part of body are taken into consideration in this model. The fundamental control actions of the rider are as follows;

(1) The main control action of a rider is the steering torque.

(2) He tries to keep the motorcycle upright and follows the course.

(3) To keep the motorcycle upright, he inputs torque into the handle bar in proportion to the roll angle.

(4) To follow the course, he inputs the torque into the handle bar in proportion to the future deviation from the previewed ahead target course.

(5) The rider supports the steering behavior by the action of his lower part of body and moves his upper part of body only to keep his head position constant.

(6) The input torque from the rider follows the following equations,

\[ \tau_s = K_s \phi + K_{su} \cdot d \] (1)
\[ \tau_S = K_S \phi + K_{Su} \cdot d \] (2)
\[ \tau_L = K_L \cdot \phi + K_{Ld} \cdot d \] (3)

(\( \tau_s \): steering torque, \( \tau_S \): upper body torque, \( \tau_L \): lower body torque, \( \phi \): roll angle, d: future deviation from the previewed ahead target course)

(7) Coefficients \( K_{S}, \ldots \) etc. changes co-responding to the speeds and riding situations.

By combining these rider models and motorcycle models, Katayama and his group made computer simulations of this rider-motorcycle system and confirmed its validity by comparing them with results of real vehicle experiments in five different situations. The basic steering model is primarily a linear predictable control model and the rider controls the motorcycle by the steering torque, upper and lower body torque. The summaries of the comparisons as follows:

1. Slalom riding situation
   It can be reproduced by the basic riding action model.

2. Lane change situation
It depends on each rider extremely, but it can be reproduced by the basic riding action and course adaptation model.

(3) Side-wind situation
It can not be reproduced by the basic riding action model. To reproduce it properly, the holding action in which the steering angle must be kept constant for 0.4 or 0.5 seconds after the entrance into the turbulence is essential.

(4) Non-steady situation (entering from a straight course to a corner)
The response delay time must be introduced to the steering and upper body torque. It seems to be a program-like control action.

(5) Slow speed situation
When the speed is low, the gyro-moment becomes small and therefore the stability of the motorcycle becomes low. Experimental results can be reproduced by a modified model which adds the steering torque in proportion to rolling velocity.

The basic control action model and the modified models according to each task can represent the rider’s basic steering actions. We believe there is no model that can represent all of the riders’ behaviors. There should be several models that suit rider’s basic action respectively.

4. THE PROPOSAL OF A NEW MOTORCYCLE SIMULATOR

Using the current motorcycle simulators, we cannot reproduce the models and equations, which we mentioned above. This is not because the current dynamic equations of the motorcycle have any error but because the mechanism and control algorithms of the riding simulators are not efficient. Therefore, we are now developing a new motorcycle simulator. The system configuration and the appearance of the simulator is shown in Fig. 3 and Fig. 4.

![Fig. 3 System Configuration of the Motorcycle Simulator](image1)

![Fig. 4 Appearance of the Simulator](image2)

4.1 Outline of the simulator

**Motion System.** We employ a parallel manipulator of six degrees of freedom to plan the motion of the platform. This motion platform has been utilized in order to realize the inertial feedback on the rider. The parallel manipulator plays an important role in the realization of complete simulators due to its capability of stiffness, accuracy, and high bandwidth. It posses a good payload-to-weight ratio which is a basic requirement for good motion platforms. We can choose the rotational centers of roll, pitch and yaw of the motorcycle simulator by combining the rotational and horizontal movements.

**Visual & Audio System.** We use a head mounted display (HMD) and a headphone. HMD is one of the displays which has been developed in the field of Virtual Reality. Different from a fixed display, it is useful for producing a complete closed virtual space to a rider of the simulator. HMD is equipped with a polhemus sensor, which can measure the position and the posture of the rider's head, and so a rider can get a picture in accordance with the movement of his head.

It is possible to hear the engine noise, the other vehicles noise and the reflection of the sounds over the surfaces close to the rider in the virtual environment. The sound sources change depending on the position of the rider's head.

**Dynamics System.** This is a dynamic planner to compute the real trajectories of the motorcycle. The inputs of this dynamic system are the actual commands of the rider. In order to reproduce the motion of a real motorcycle, a state of the motion is calculated from the model of a motorcycle. A motion model is divided into two parts, longitudinal motion and lateral motion. A model of longitudinal motion is almost same as the one of the vehicle. We use a Sharp's model of four degrees of freedom as a model of lateral motion. Results of the calculation are sent to Motion System and Visual & Sound System.

4.2 Control Algorithms of the Motion Platform
It is generally said that a rider of real motorcycle don't feel roll angular acceleration very much when he turns. It is because a rider tries to turn with his lateral position of head fixed as possible as he can. The current motorcycle simulators have a center of rotation at the lower part of the mock-up. In this case, rider feels such force as his head is swung by the angular acceleration of the simulator. In order to reduce this undesired head movement, we set the center of rotation of the simulator movements on the rider's head as shown in Fig.5. We think that by reproducing similar motion to real motorcycle, we can reproduce the details of the real feelings of a motorcycle.

Control Algorithms are divided into two parts, Motion Planner and Washback.

Motion Planner decides the motion of the manipulator by calculating the acceleration from the motion equation of a motorcycle.

Washback puts the manipulator back to the neutral position in the way not to be perceived by a rider in order to make up for the limit of the motion range of the manipulator.

5. EXPERIMENT

The purpose of this research is to reproduce the real feeling of a motorcycle. We evaluate our simulator using a control algorithms mentioned above.

We have the subjects ride along the course which contains lane change every 500m. We build two Motion Planners, one is a Motion Planner by which simulator moves with its rotation center on the rider's head and the other on the road. Each subject is said to fill out a questionnaire.

Fig.6 shows the steering torque and lateral position of the motorcycle.

Result of the questionnaires is shown in Fig.7. It can be said that the former algorithm reproduces more real feelings.

6. CONCLUSIONS

i. We made a survey on primary developed motorcycle simulator in Japan and found that the mechanism of the primary simulators is not efficient to reproduce the real motorcycle feeling.

ii. We developed a motorcycle simulator using parallel manipulator and head mounted display.

iii. We proposed a new control algorithm of a motorcycle simulator and confirm a validity of it by the experiment.

REFERENCES