A Study on Riding Simulator for Motorcycle

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This paper describes the construction of a riding simulator for motorcycle. This simulator is constructed by using the results of experimet for motorcycle dynamics. This motorcycle simulator is capable of simulating speed close to a real motorcyle. Thus, it can also be used to assist study on Human-Machine Interface(HMI) and evaluation of total motion characteristics between human and motorcycle.

1.Introduction

As motorcycles have unstable characteristics at a certain range of speed, they need to be controlled with proper stability. However, there is a possibility that the rider may de-stabilize motorcycle. At this point, it is plausible to say that the movement of a motorcycle is greatly affected by its rider. Therefore, a rider himself and the vehicle itself are two important factors in the analysis of the motorcycle behaviour. It is undeniable that to perform such analysis and experiments with a real rider as test subject are difficult and dangerous. Moreover, to perform tests that require repetitions of the same condition is also impossible. There is also a need to consider that a motorcycle has very limited space for mounting measuring devices. Considering these problems, it would be wonderful if such experiments could be conducted with a simulator that simulates reality without the unnecessary hazards. Thus the use of the Riding Simulator (RS) would be an effective solution to these issues.

Upon analyzing at the data of traffic accidents that happened in the recent years, it can be deduced that one fifth of these fatal accidents involved motorcycles. As one of the methods to reduce accident, the research for improvements on 'passive safety' and 'active safety' of motorcycles and also researches on improvement in maneuverability and stability of motorcycles should be done. Unlike a four-wheeled vehicle, the rider's body is not protected by the vehicle body; thus an improvement over 'active safety' systems will be an effective way to reduce accidents. In other words, accidents can be reduced by providing information of dangerous situations in advance to the rider. In connection with these situation, the Ministry of Land, Infrastructure and Transport Japan aims to promote research and development of automobile safety technologies, making researches on vehicle ASV vigorous in recent years. Three out of four domestic motorcycle makers are using 'big scooters' as target vehicles for ASV application. The reasons are; higher storage capacity, an improvement in operability by automatic transmission, and recent establishment of the new motorcycle license limited for automatic transmission in Japan. It is because there is such background in the first place; there will be many possibilities to develop such vehicles in the future.

As mentioned before, this research is aimed at the analysis of the motion characteristics of human and motorcycle systems. Therefore, the purpose of this research is construction of motorcycle simulator for the HMI on ASV.

2. The composition of the simulator system

In reality, a rider controls the motorcycle simulator by using his/her senses of sight, hearing, sense of movement, control and also cutaneous sensation to recognize the current state of the vehicle. These information are then processed and used to maintain the vehicle stability, and to control along the intended directions. This simulator is set to monitor various variables generated for example, (1) the accelerator, (2) front and rear brakes to understand the speed control, (3) the steer torque applied to the steering handle to control the lateral motion of the vehicle, and (4) the reaction force between rider and the seat. When these inputs are added, the main computer calculates the amount of the vehicle output using the vehicle model. The model is as follows; (1) engine model, (2) longitudinal motion model which includes two degrees of freedom, and (3) lateral motion models which includes four degrees of freedom. By combining each of these, the final vehicle output can be calculated. From the calculation result of these vehicle models, simulated behavior is then generated back to the rider in the form of virtual reality. These feedbacks are then each simulated by different equipments. Specifically, these equipments are able to simulate movements, visions in the form of projected image, sound effects and artificial winds. Fig.1 shows a block diagram of the simulator external outline and Fig.2 shows a schematic diagram of the simulator system.

2.1. Motion device for the simulator

The motion of this riding simulator has three degrees of freedom, roll-axis, pitch-axis, and steering-axis. At each of these axes, three AC servo motors are placed to operate and control the vehicle body movement. The angles, which are controlled by the servo motors, are set to have movable range of ±15° for pitching, ±20° for rolling, and ±10° for steering. Setting these angles beyond the values of the range written above could be dangerous, so an emergency stop button is also included in the system to prevent fatal accidents.

2.2. Visual system for simulator

The front view images are generated by a computer and then projected onto a screen installed in front of the system. The horizontal angle of visibility is 150°, and the vertical angle of visibility is 35°. By utilizing these angles, the simulator can be described the forward image when the vehicle turns. A 3D graphics development software called Blue Impulse is used in the development of the visual counterpart.

2.3. Sound simulation system

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

2.4. Wind Generator Device

A set of wind generator is set in front of the steering handle to give a running feeling to the rider. Additionally, the amount of wind generated depends on the speed simulated at that moment. The wind generator is placed strategically after careful consideration of the generated wind strength, range, and the rider's vision range is done. With the inclusion of this wind generator the rider feels a more realistic riding experience.

2.5. Control Devices

Motion information, motion simulation, rider's input and movement of the servo motor are all programmed to be controlled by computers. The analog signals are converted to the digital data by AD/DA converter.

In addition, a combination Local Area Network (LAN) system and TCP/IP protocol system are used to provide inter-communication between the various devices. For example; data information such as x-y image coordinates, roll-angle, and yaw-angle are also transferred by computers.

2.6. Control System

In order to able to monitor the model parameters by offline and by online in real time, a Digital Signal Processor (DSP) is installed. This means that the system allows the parameters to be altered and the result will be displayed and reflected at real time. In addition, the benefits using this system is as follows; (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, (2) the system allows the changes instantaneous feedback from the rider. A flow chart of the DSP embedded Motion Control System is shown using SIMULINK in Fig.3. And the flow chart of the artificial wind, sound and visual control system is shown in Fig.4

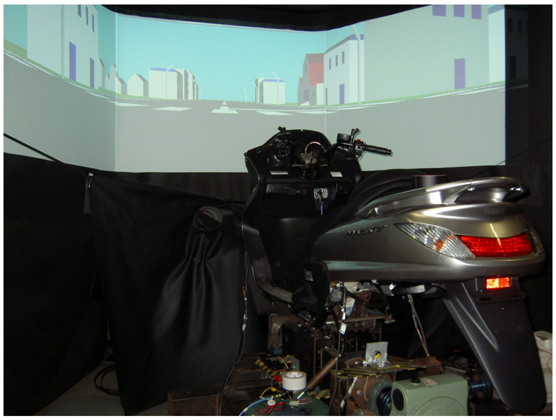

Fig.1 An image of the Riding Simulator

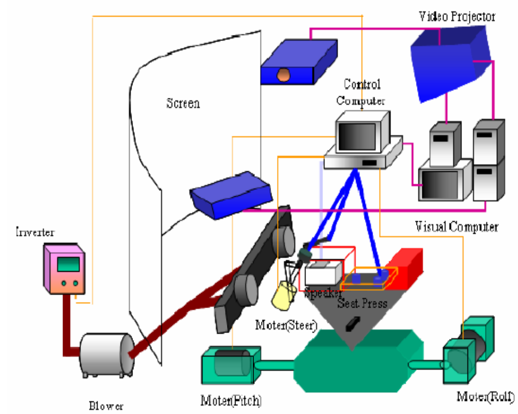

Fig.2 Riding Simulator System

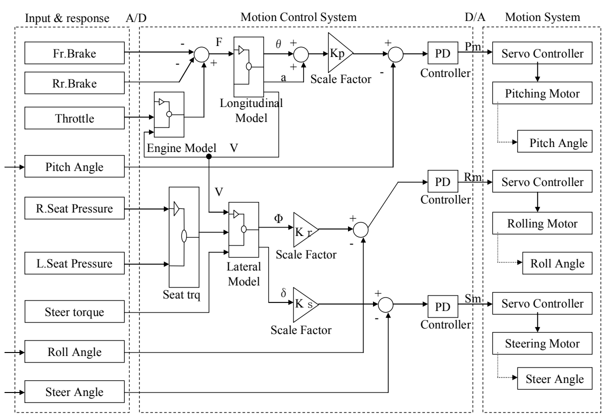

Fig.3 Motion Control System

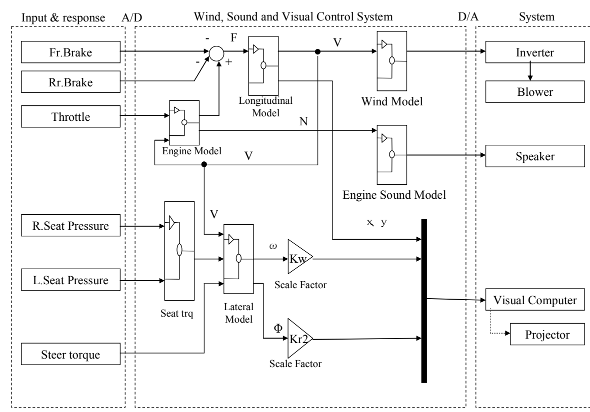

Fig.4 Artificial Wind, Sound and Visual Control System

3. Lateral motion model

3.1. The motorcycle movement

At present, most equations of motion for a motorcycle are comprised of four degrees of freedom. By using the Sharp’s model, it is well known that three modes, two are vibration mode called ‘weave’, and ‘wobble’, and one non-vibration mode called ‘capsize’. The weave mode has a natural frequency of 1 - 4 Hz; and the wobble mode has a high-frequency of 6 - 10 Hz. Therefore, it is impossible for the rider to control a motorcycle when such high-frequency wobble vibrations occur, especially while the vehicle runs, at high speed it turns to be unstable. 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 equations of motion could express the characteristic of a real vehicle relatively well however it is not perfect. By using eigenvalues and then correcting it, these equations of motion can be used as lateral directional motion models for the simulator.

To achieve several purposes such as to simulate lateral movements and also ultimately best express the characteristics of a motorcycle and lastly to construct models that could run stable at various speed, the roots of characteristics equations are thoroughly revised.

3.2. Construction of lateral motion model

The first step is construction of basic lateral equations of motion. Using these equations, the transfer functions are calculated. Even though these equations do not represent the exact actual movement of the vehicle, these equations could give a rough image on how the motion would be like in real situation. At this point, we need to consider other forces such as cornering force, camber thrust, self-aligning torque, and gyro-moment. In terms of degrees of freedom, the other factors that also need to consider are the steering angle, the roll-angle, the yaw-rate, and the lateral speed. The next step is deriving eigenvalues from the equation of motion. An approximate value of natural frequency (ω_n), damping ratio (ζ), time constant (T), and system gain (K) can be found. These values are then rounded up. To alter the stability of the system from unstable to stable, the values of the damping ratio and the time constant are also corrected. Upon achieving that, each value is calculated using appropriate equations. The roots of the equation are also corrected so that unstable values would become stable. Only after going through these processes, a model of motorcycle that is stable at variable speed and has all the basic characteristics of a motorcycle are then completed.

Using the coefficients derived from the above process, the transfer functions for the simulator can be determined. Factors such as steering angle (δ), rolling angle for simulator body (Φ_w), the rolling angle for computer graphics (Φ_c), yaw rate (ω), and lateral velocity (V_y), are the factors that are required to simulate a motorcycle. Most of them are just a form of inputs by the rider. In addition to these, the vibration modes are also further improved, this is due to 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 follows;

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

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

$$\frac{\phi_c}{T_h} = \frac{K_{\phi_c}}{T_1 s + 1}$$

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

$$\frac{V_y}{T_h} = \frac{K_{V_y}}{T_1 + 1}$$

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

$K_{\phi_w} = \{-7.5\times10^{-4}\}$

$K_{\phi_c} = \{-1.2\times10^{-2}\}$

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

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

$V = velocity$

Using the velocity derived from the calculations above, stability examinations of the lateral movement models could be performed. As mentioned before, the models consist mainly of three main modes such as ‘capsize’, ‘weave’ and ‘wobble’ respectively. After some experiments, it is proven that the model is able to maintain stability at any speed, which means the models, would be user-friendly.

Changes in the center of gravity of the simulator rider can be figured out by examining certain changes in the load value. This can be achieved and calculated after placing ‘load-cell’ in the inner compartment of the simulator. To calculate the input value of the simulator, we need to put several variables value in the equations. These variables consist of ‘seat-moment’, addition of steering torque, and also after consideration of first-order lag term, the equation can be written in the following form:

$$Input = T_{st} \times \dot{M}_{st} + M_{st} + T_s$$

In this equation, T_{st} is the time constant to the seat moment M_{st}. 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 less uncomfortable moment.

3.3 Lateral Motion Simulation

At this part of the paper, there will be explanations on lateral simulation model that involve factors such as calculations of yaw-angle, roll-angle, and the resultant yaw-motion. Firstly, yawing motion are simulated by using front view and calculated by using lateral motion model. At the next step, the value of the yaw angle is then entered to a computer for further process. Unlike the real motorcycles, the riding simulator does not produce much of centrifugal force which could give an unrealistic feeling for the rider. In order to overcome this problem, plenty of visual screen images and roll-motion are used to give the rider a realistic feeling as much as possible. Moreover, to simulate a realistic capsize motion, light shaking of screens is also used. The systems are then also further tuned so that the rider would not feel any discomfort or experience any hazards by excessive screen vibrations. However, by just simulating capsize motion would not be enough, weave motions are also generated by utilizing the simulator body vibrations. First, by using lateral motion model and potentiometer, the simulator target roll angle can be calculated. Next, by using a PD control the difference between the present roll angle and the target roll angle is calculated. This information is sent to the PD control system and then the final output is sent to AC servo motor.

4. An application using the simulator

In this project, there is a limit on how much speed is allowed to be simulated, therefore, the 'Riding Simulator' cannot be used to assist in analyzing situations that requires at high speed. However, the simulator itself is able to simulate motions realistic enough such that experiments which involve human factors, such as fatigue, drunk driving, and dangerous traffic condition, can be safely and realistically simulated. Therefore, it can be concluded that this simulator is a suitable (piece of equipment) for conducting experiments on the relation between human and motorcycles.

Additionally, this simulator can also be used to simulate various type of motorcycle by mounting different types of chassis. This simulator has beneficial potential on developments of traffic systems such as; (1) traffic information structure, (2) evaluation of information flow system, (3) information priority, (4) analysis of rider's information to control the vehicle, and also the evaluation of HMI.

5. Conclusion

This research has managed to achieve its main goal in the construction of human-controllable two-wheeled riding simulator, and it also has managed to achieve other goals in the process such as the description and analysis of the relation between human and motorcycles. Ultimately, this research would help the advancement of human-machine interfaces in ASV systems.

By using this simulator we would like to conduct further researches on human-machine interface and human driving characteristics.

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