# Development for Tilting Train Dynamics Motion Base

Yong-Soo Song*, Seung-Kwon Shin, Jung-Seok Kim and Seong-Ho

*Korea Railroad Research Institute, Uiwang-city, Kyonggi-do, Korea
* (Tel : +82-31-460-5668 ; E-mail:adair@krri.re.kr )
(Tel : +82-31-460-4537; E-mail: skshin@krri.re.kr)
(Tel : +82-31-460-5678; E-mail: jskim@krri.re.kr)
(Tel : +81-31-460-5660; E-mail: shhan@krri.re.kr)

Abstract: This paper describes the construction of a half sphere screen driving tilting simulator that can perform six degree-of-freedom (DOF) motions simulator to a tilting train. The mathematical equations of Tilting Train dynamics are first derived from the 6-DOF bicycle model and incorporated with the bogie, carbody, and suspension subsystems. The equations of motion are then programmed by visual C++ code. To achieve the simulator functions, a motion platform that is constructed by six electric-driven actuators is designed, and its kinetics/inverse kinetics analysis is also conducted. Driver operation signals such as carbady angle, accelerator, and tilting positions are measured to trigger the Tilting dynamics calculation and further actuate the cylinders by the motion platform control program. In addition, a digital PID controller is added to achieve the stable and accurate displacements of the motion platform. The experiments prove that the designed simulator is adequate in performing some special rail road driving situations discussed in this paper.

**Keywords:** Tilting simulator, Motion base, Train dynamics

## 1. INTRODUCTION

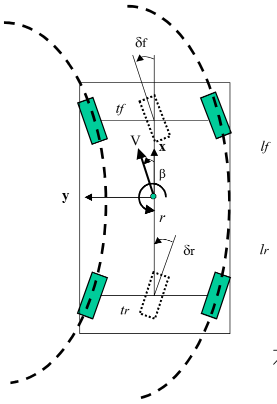
The continuing advance in computer technology has made the application of PCs in several engineering fields, such as computer graphics and virtual reality (VR) technology, come true. Consequently, due to the increased commercial demands and research interests, various types of simulators have been developed. Among them, the flight simulator is the most successful development, followed by the driving simulator for railroad tilting train.

The application of the tilting train is one of the most efficient ways to increase curving speed of train on existing tracks or on mountain railway lines with sharp curves. It can increase the running speed and ensure the passenger comfort and safety at the same time. Therefore, the development of tilting train has been paid high attention by many countries in the world. Tilting trains have been operated successfully in many countries such as Italy, Spain, Germany, Sweden, England and so on. The tilting trains possess broad prospects in raising speeds.

## 2. TRAIN DYNAMICS ANALYSIS

The train subsystems that affect vehicle dynamics include the bogie, steering system, suspension system, and SIV, CI systems. In addition, many external factors, such as the centenary inputs of the railway conditions, the grade of the rail, the bolster load and its electromechanical actuator, the the secondary suspension and its direction, as well as its interaction with the carbody and under-frame components, will have an effect on train dynamics as a whole. As a result, vehicle dynamics is so complex that analyzing the influences of all vehicle subsystems and external factors simultaneously is not an easy task. Thus, in order to look closely at the details of each influencing factor, we can analyze their characteristics one at a time and then integrate several of them to study their interactions.

It is convenient to treat the carbody as a rigid body with six degrees of freedom; its body-fixed coordinate system is shown in Fig. 1,2 [1], [2].



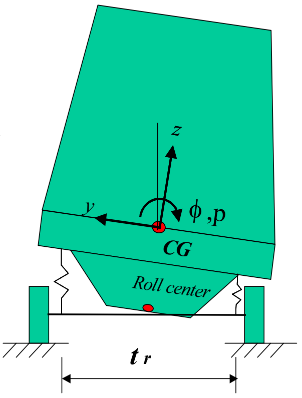


Fig. 1 (a) In-plane view Fig. 2 (b) Side view

The three linear movements of the carbody to the ground are longitudinal, lateral, and vertical velocities along x, y and z directions. They are defined as u, v and w, respectively. In addition, the roll, pitch, and yaw rates are the angular velocities of the body about x-, y-, and z-axes [1].[3]. With some specific constrains for different interests, the degrees of freedom of the tilting carbody can be further reduced. For instance, a 6-DOF (lateral velocity and yaw rate) train model with active tilting bogie (Fig. 3) can be used as a simple vehicle model in some analysis cases.

$$R = u\hat{i} + v\hat{j} \quad [1]$$

$$\dot{R} = \dot{u}\hat{i} + u\dot{\hat{i}} + \dot{v}\hat{j} + v\dot{\hat{j}} \quad [2]$$

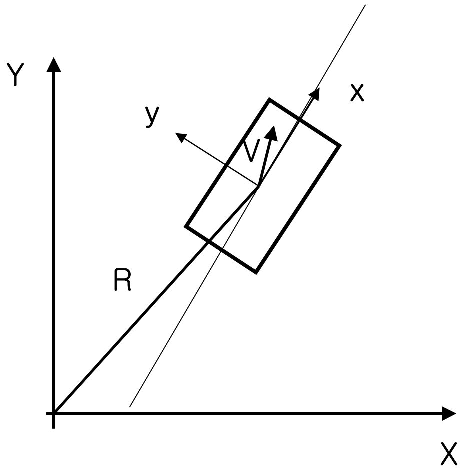


Fig. 3 Vehicle fixed coordinates system

As shown in Fig. 4, while cornering, the tilting carbody tends to roll out of turn due to the nonrigidity of the suspension system.

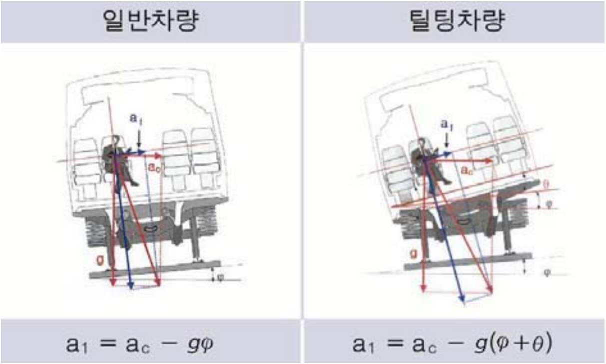
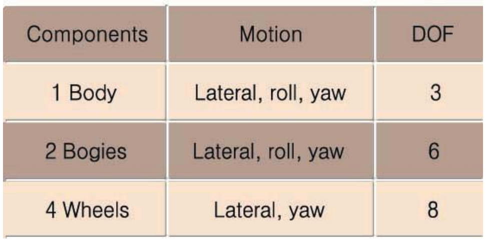


Fig. 4 Rolling of a simple Train in cornering

Let the suspension system be represented by two springs at each axle; then the roll angle is a function of the lateral separation between the bogies, carbody, lateral actuators, and train weight, as well as the position of the rollcenter . Thus, the roll axis is the instantaneous axis about which the damper mass rotates with respect to the sprung mass when a pure couple is applied to the damper mass. As the figure shows, the roll axis can be simply defined as the connection of the suspension roll centers.

For the vehicle shown in Figs. 4, 5, 6.and its time rate , and pitch and its time rate are zero.



| Components | Motion | DOF |
|---|---|---|
| 1 Body | Lateral, roll, yaw | 3 |
| 2 Bogies | Lateral, roll, yaw | 6 |
| 4 Wheels | Lateral, yaw | 8 |

Fig. 5 motion's force component

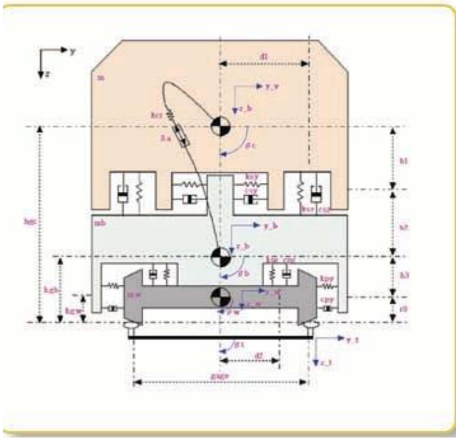


Fig. 6 Tilting system and restoring torque.

## 3. DESIGN AND CONSTRUCTION OF A 6-AXIS MOTION PLATFORMFONTS

Due to the increased commercial demands and research interests, various types of simulators have been developed.

To represent a Train in the driving simulator, a motion platform that can produce 6-DOF motions is required. Currently, Steward platform is the most popular six-axis motion platform. In reality, the train longitudinal motion can hardly be produced in a simulator. But, in this study, the authors utilized only Six cylinders to construct a motion platform that can produce 6-DOF motions (Fig. 7).

As shown in Figs. 7.10, six cylinders are installed to plate by ball bearings on the basement. Therefore, plate can be actuated by these six cylinders and move in plane to simulate vehicle lateral translation and yaw motion for some specific analysis interests.

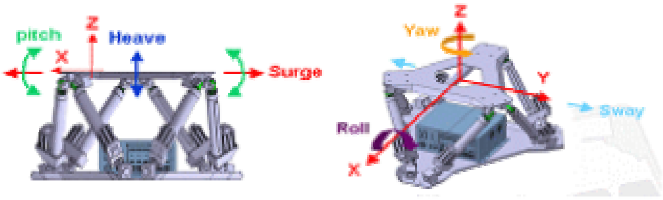


Fig. 7 Roll, pitch, and vertical motions of plate

Table 1 SPECIFICATIONS OF THE MOTION PLATFORM

|  | Range | Velocity | Acceleration |
|---|---|---|---|
| Pitch | ±18° | ±30°/s | ±300°/s2 |
| Roll | ±15° | ±30°/s | ±300°/s2 |
| Yaw | ±18° | ±30°/s | ±300°/s2 |
| Heave | ±7.5cm | ±40cm/s | 0.5G |
| Surge | ±8cm | ±40cm/s | 0.5G |
| Sway | ±8cm | ±40cm/s | 0.5G |

The completely constructed driving simulator consists of a six-axis motion platform mentioned above, a train dynamics analysis and motion control computer, a virtual reality computer, three potentiometers, and three analog-to-digital/ digital-to-analog converter (ADC/DAC) cards. The graphical representation is shown in Fig. 8. Also, for the safety of the driver (operator), a capsule is welded to plate in Fig. 7, and a driver's seat used exclusively for train taken apart from a train re installed.

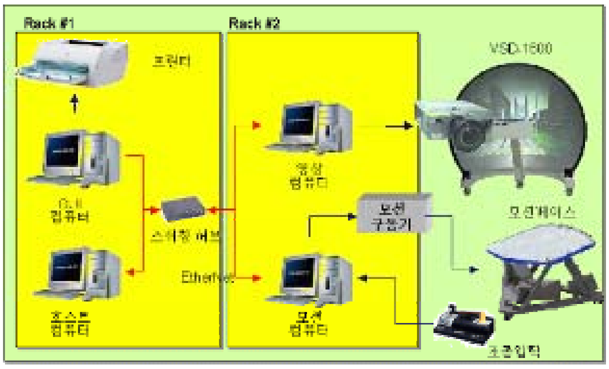


Fig. 8 Graphical representation of the Tilting simulator.

A PowerPC 450 MHz, equipped with 16 MByte flash memory, RS232 interface with standard UART, A/D 20 channels (12 it) , /A 8 channels (12 bit) and 4 CAN controller, executes the numerical analysis of Train dynamics and the control of motion platform. The mathematical equations of vehicle dynamics are programmed in MATLAB, transferred into visual C++ codes by SDI, and integrated by C++ Builder into a control code.
The tilting angle and carbody and actuator positions are encoded into analog voltages by transformers, acquired by SIM(fig 9), converted into digital signals, and sent to vehicle dynamics analysis programs.

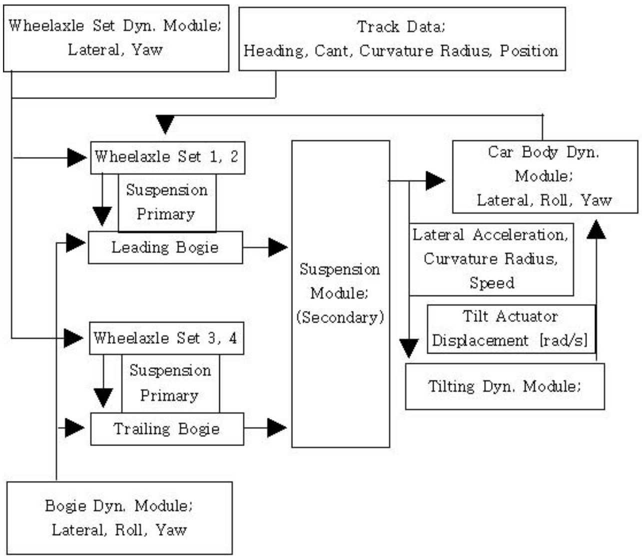


Fig. 9 Equation of Motin Flow

The Train's longitudinal, lateral, and vertical displacements, as well as roll, pitch, and yaw angles, are carried out and transferred into required actuation voltages, converted into analog signals, and sent to cylinders by actuator driver.
Also, the Train's position and required cylinder lengths are carried out by the motion platform kinematics/inverse kinematics analysis, and the System (MTM) in motion platform detect the actual lengths of the cylinders and feed them back to the PID controller for closed-loop control.

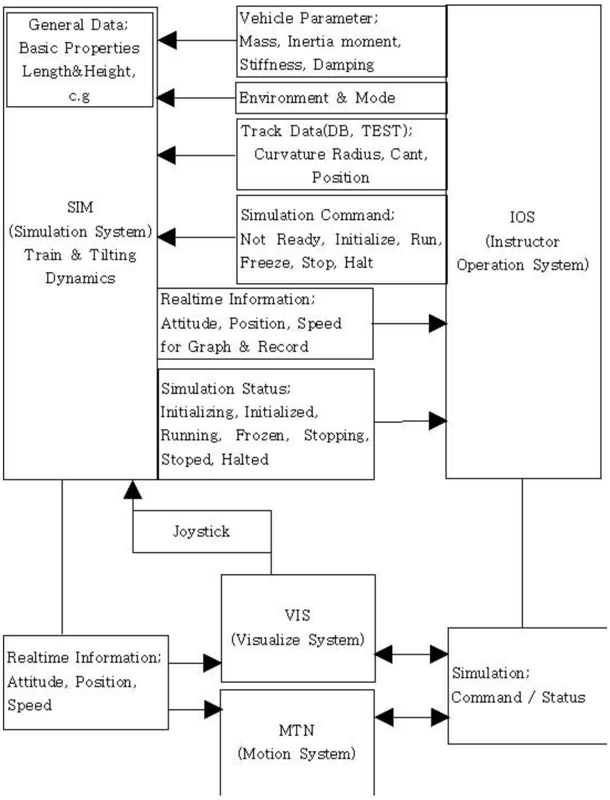


Fig. 10 Data Receive & Transmit

Fig. 11 VR environment of the constructed driving simulator.

## 4. INTEGRATION OF DRIVING SIMULATOR,RESULTS, AND DISCUSSIONS

The major results of the study reported in this paper are as follows.

1) A full Train dynamics simulation program is developed using MATLAB that can be employed either in off-line

analysis and simulations or in on-line

2) A six-axis motion platform is constructed and calibrated; its kinematics/inverse kinematics is analyzed, and thus can perform 6-DOF motions similar to the motions of a Tilting train.

3) A virtual reality environment that is used to simulate the x-direction motion and to aid the video/audio presentation is constructed. Also, the integration of different software and hardware is accomplished.

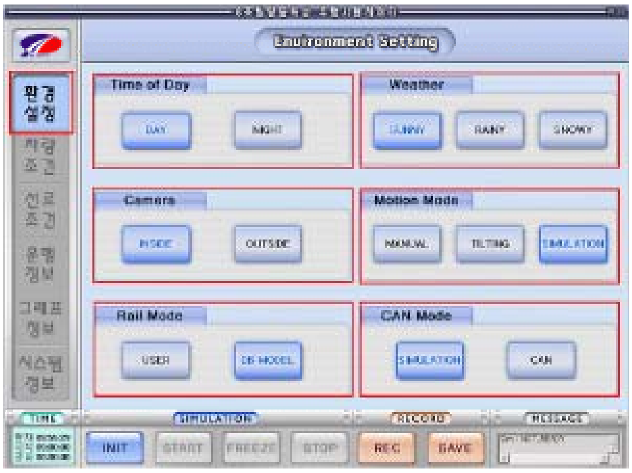


Fig. 12 GUI of the control program

The graphical user interface (GUI) created by visual C++ displays not only the numerical values of the vehicle motion ariables but also the trajectory of each degree of freedom, as hown in Fig. 12. The constructed driving simulator is shown in Fig. 13

Fig. 13 The constructed driving simulator.

## 5. CONCLUSIONS AND FUTURE WORK

This paper describes the construction of a six-axis driving simulator based on vehicle dynamics analysis and system integration. C++ Builder makes available many GUI design functions superior to MATLAB.

The constructed six-axis motion platform can perform lateral and vertical displacements and roll, pitch, and yaw motions similar to the 6-DOF motions of a tilting train while the longitudinal translation is simulated by VR technology. Even though the lateral velocity and yaw rate are scaled down to about 1/10 due to some inevitable limitations, the driving simulator can imitate the road vehicle motions in many normal driving situations. In the future, more powerful computers can be used to increase the number of frames per second and to speed up the numerical calculation. Also, a rail surface model and more complex train models, such as the including of power train system, can be adopted.

## ACKNOWLEDGMENTS

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