Development of a Full-Scale Driving Simulator for Human Sensibility Ergonomics Study

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Abstract

A full-scale driving simulator is being developed as an effective test-bed for reproducing realistic driving situations in a safe and tightly controlled environment and conducting various human sensibility ergonomics studies. The simulator will be equipped with a 6 degree-of-freedom, high frequency motion base and a 4 channel, wide field-of-view visual system. The simulator will be fully interactive, highly realistic, and yet economical, taking advantages of the fast growing PC technology.

Keyword : Driving Simulator, Human Sensibility Ergonomics, Real-time Simulation, System Integration

1. Introduction

The human sensibility ergonomics technology concerns measuring and indexing human sensibility qualitatively and quantitatively, and applying the indexed database to design of products and environments that will lead to more convenient, more comfortable and safer human life [1]. In developing the technology, a test-bed, capable of creating physically meaningful situations in a safe and tightly controlled environment, can become a useful research tool for various sensibility ergonomics studies.

A driving simulator is a virtual reality tool that gives a driver on board an impression that he/she drives an actual vehicle by predicting vehicle motion caused by driver input and feeding back corresponding visual, motion, audio and proprioceptive cues to the driver. The simulators have been used effectively for vehicle system development, intelligent transportation systems research, traffic safety improvement and human factor study [2,3].

This paper describes the development of a full-scale driving simulator chosen as a test-bed for sensibility ergonomics study, which is a part of Human Sensibility Ergonomics Technology Development Project. The simulator, expected to be operational in the middle of 2001, will be fully interactive, highly realistic, and yet economical, taking full advantages of the fast growing PC technology and authors' rich experience related with driving simulators.

2. System Configuration

Figure 1 shows a conceptual drawing of the driving simulator installed in a dedicated research facility at Korea Research Institute of Standards and Science. Figure 2 shows a

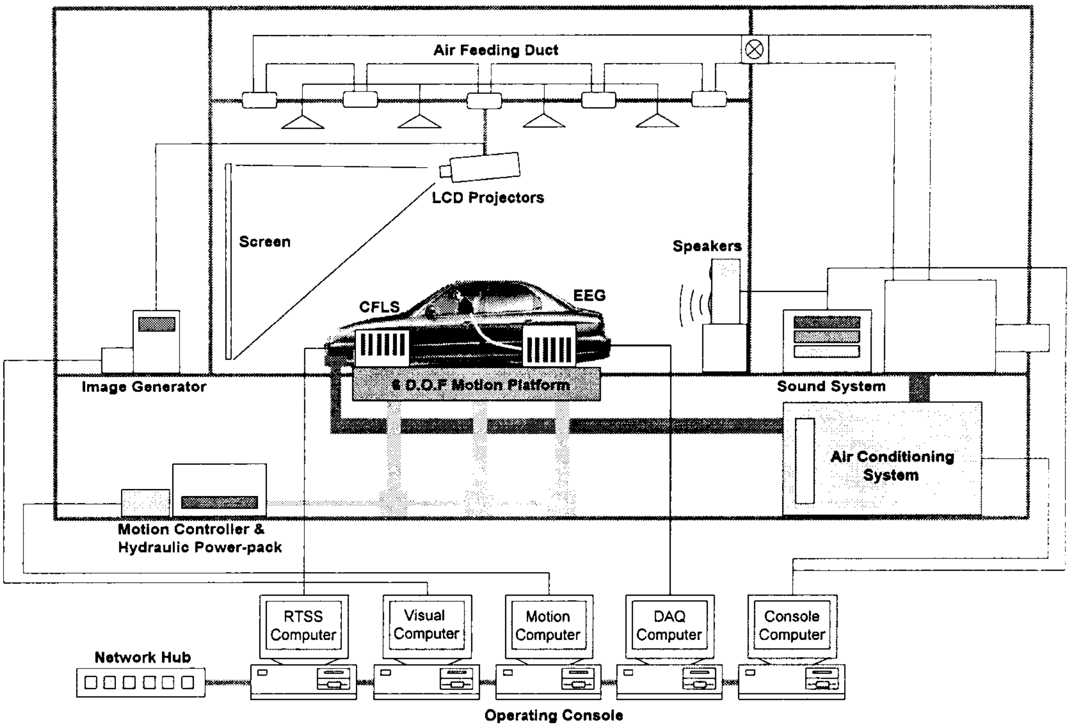

Figure 1. Conceptual Drawing of the Driving Simulator

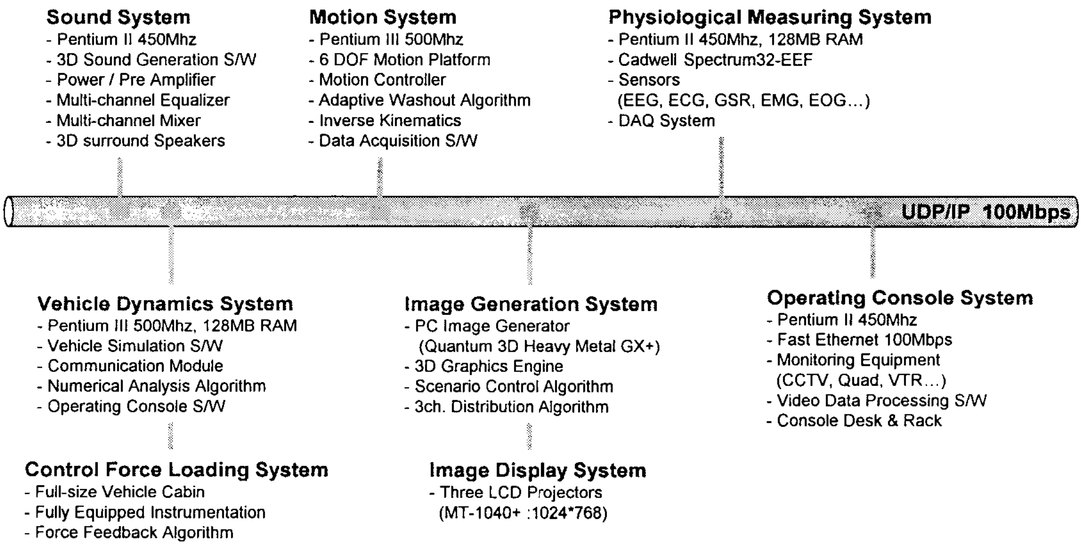

Figure 2. System Configuration of the Driving Simulator

general configuration of the driving simulator. It is a full-scale simulator with a 6 degree-of-freedom motion base and a 4 channel, wide field-of-view visual system. The simulator is controlled and operated in a network of seven personal computers connected by Ethernet.

Real-Time Vehicle Simulation System

The real-time vehicle simulation system is a key element of the driving simulator because accurate prediction of vehicle motion with respect to driver input is essential in assuring the high fidelity and realism of the simulator.

In order to predict vehicle motion caused by various driving actions of the driver on board the simulator, the vehicle models should include, in addition to basic chassis and suspensions, subsystems such as an engine, a power train, a steering system and a brake system. The models should also have flexible expandability based on a modular structure.

Figure 3 shows a vehicle dynamic analysis module. For chassis and suspension motion, a 14 degree-of-freedom full vehicle model has been developed. Based on a simple linear relationship between the accelerator pedal angle and the throttle valve angle, the input to the engine model has been determined according to driving action. The engine speed and torque have been computed using a simple engine model based on the reference 4. A power train model, consisting of a static torque converter and an automatic transmission with a transmission map, has been used to compute driving torque that will be included in tire rolling dynamics. For the brake system, a quasi-static model has been used to compute brake pressure in relation to the brake pedal angle, without considering hydraulic system dynamics. The steering system has also been simplified to account for a rack and pinion type. The vehicle model runs on a typical PC with an integration step size of 2 msec, thus enabling reliable real-time simulation.

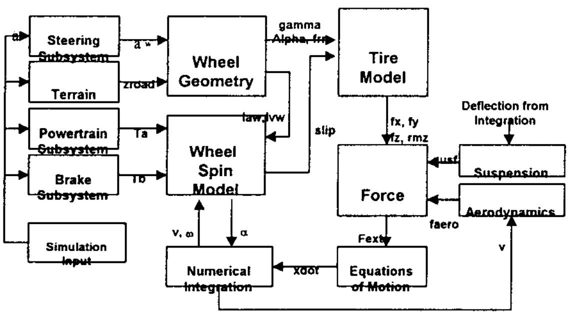

Figure 3. Vehicle Dynamic Analysis Model

A monitoring console software, as shown in Figure 4, has also been developed to monitor on-line simulation of vehicle dynamics by examining information on the vehicle states and forces. The software also allows off-line simulation of vehicle dynamics with inputs from keyboards, joysticks and other sources for convenient test and evaluation of vehicle model performance.

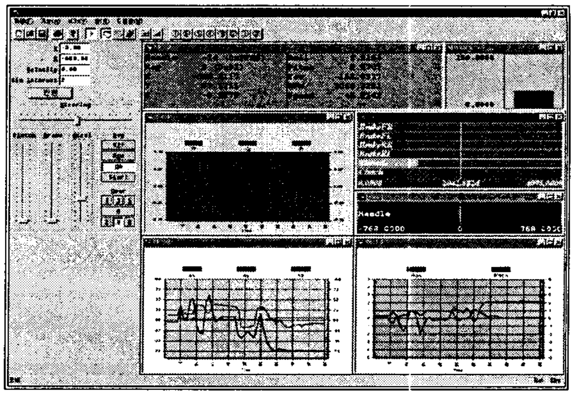

Figure 4. Monitoring Console Software

Visual and Audio System

Since visual cue is most significant in controlling and maneuvering a vehicle during driving, the key element for ensuring high fidelity in driving simulation is a visual system. Processing of high-resolution graphics in the visual system is essential for the driver to have realistic driving feel and react to driving environment precisely. The visual system is divided into two parts for computer image generation and display. Figure 5 shows a functional diagram of the 3D graphic generation module.

The visual systems in the full-scale driving simulators normally utilize very expensive high-end workstations with dedicated graphic cards and graphic software to generate high fidelity visual image [5]. On the other hand, our image generation system is based on PCs with fast 3D graphic accelerator cards taking full advantages of fast developing PC graphics technology. A graphics engine based on OpenGVS [6] has been developed for fast and easy creation of graphics databases and ensuring highly realistic and smooth graphic images with over 30 frames/sec refresh rate. Figure 6 shows a typical driving scene. A four-channel LCD projection system will be developed to display front and rear-view images with 150 x 40 and 60 x 40 degrees of field-of-view, respectively.

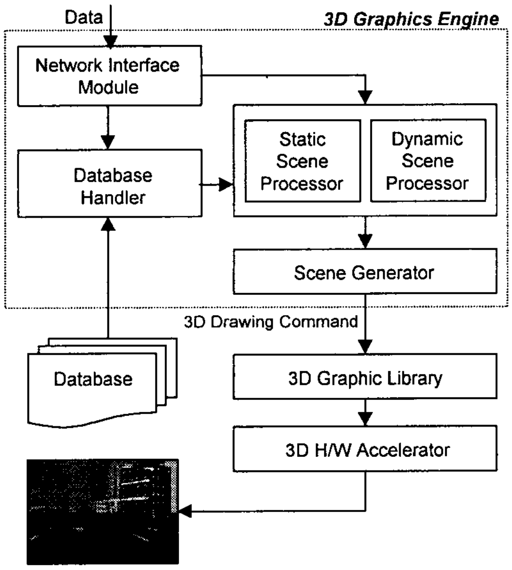

Figure 5. 3D Graphic Generation Module

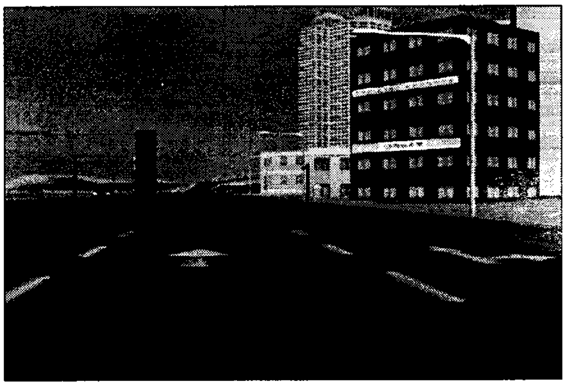

Figure 6. Typical Driving Scene

An audio system is an important addition to fidelity enhancement of the driving simulator. The audio system has been set up with a consumer PC sound card and speakers. A sound database has been constructed to store and manage tire, engine and driving environment noise. The MIDI function of the sound card has then been used to combine and play appropriate noise in coordination with driving conditions.

Motion System

Reproducing ride and handling characteristics of a vehicle that a driver feels through chassis linear accelerations and angular velocities is an important element for enhancing simulator fidelity. However, a care should be taken not to cause conflicting effects among subsystems and induce simulator sickness, due to high sensitivity of the motion system.

A 6 degree-of-freedom motion system with up to 60 Hz high-frequency characteristics will be used in our simulator [7]. A drive logic of the motion system for generating realistic motion cue includes a washout algorithm, inverse kinematic analysis, and a control algorithm, as organized in Figure 7. The vashout algorithm recovers motion cue that is realizable within the motion envelope from command cue of vehicle simulation output. A classical washout algorithm has been developed to include software limitation of platform motion based on high-pass filtering

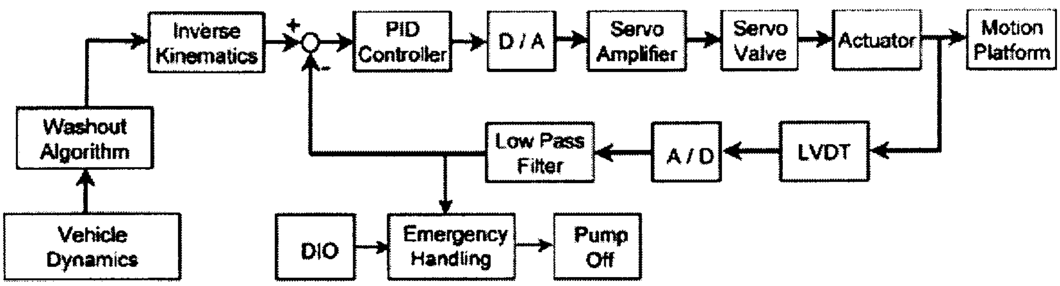

Figure 7. Motion System Functional Diagram

and tilt coordination for generating sustained inertial acceleration required in some maneuvers such as J-turn based on low-pass filtering. Chassis position and orientation information from the washout algorithm has then been converted into actuator lengths by the inverse kinematic analysis. A PID control algorithm has been implemented to ensure movement of the motion platform to the accurate position.

Control Force Loading System

The control force loading system acts as an interface between the driving simulator and the driver, in that it senses driver input and feeds the input back to the real-time vehicle simulation system, displays vehicle operating conditions on instrument panels, and generates reaction forces and torques in the driving mechanism for proprioceptive cue.

A full-car cabin with full instrumentation will be developed and installed on the motion platform. A high-frequency feedback controller based on an embedded PC will be developed to control a communication module, manage effective data transfer, activate instrumentation devices and generate realistic steering torque feedback.

System Integration

System integration, managing information and data transfer among subsystems, synchronization, and fail-safe functions, is a key factor in determining the fidelity and performance of the driving simulator. Thus, the method for integrating the subsystems should be carefully considered from the early stages of simulator development.

Table 1 summarizes the specifications of the driving simulator. The Windows NT software

Table 1. Driving Simulator Specifications

Item	Specifications
Simulator Platform	- Full-scale 6 D.O.F motion-base driving simulator
Cab	- Full-size Hyundai Accent A/T
Vehicle Model	- In-house 14 D.O.F model, STI tire model
Visual System	- General-purpose PC-base Image Generator with 3D graphic accelerator (AGP GeForce256 DDR) - Over 30 frames/sec refresh rate - NEC MT-1040+ LCD projectors - High gain grass bead curved screen - 4 ch. Front 150(H) X 40(v) and Rear 60(H) X 40(v) degree F.O.V. - Collision detection and scenario control algorithm including moving components
Audio System	- Creative Labs Sound Blaster Live Gold - Power / Pre amplifier - Multi-channel equalizer & mixer - 3D surround speakers
Control Force Loading System	- High frequency feedback controller - Fully equipped instrumentation - Highly realistic reaction force and torque generation
Motion System	- Hydraulic 6 D.O.F motion platform - Longitudinal, lateral and vertical motion of about 0.25m, Pitch, roll and yaw motion of up to 30 degrees - System Bandwidth : 60Hz - Maximum Acceleration : 9.8G
Communication	- 100Mbps Ethernet, 115,200bps RS-232C

has been chosen as the operating system of the driving simulator here, due to reliability and many convenient features. A software time interrupt function has been added to the basic Windows NT software for real-time operation.

The operation procedure of the simulator will include system initialization, a series of tests for checking normal operability and controllability, and actual simulation following driving scenarios. The carefully prepared fail-safe function will also be implemented to monitor entire system operation periodically and, when emergency occurs, move the motion platform to the neutral position safely.

3. Concluding Remarks

The fast development pace of PC technology makes low-cost, highly realistic driving simulation possible. The full-scale driving simulator developed as a test-bed for human sensibility ergonomics study, as described in this paper, can be a good example. It is expected that the simulator, when become fully operational, will be effectively applied to various studies including driving comfort, ride quality, device operability, etc.

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