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Virtual Prototyping Simulation for a Passenger Vehicle

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The primary goal of virtual prototyping is to eliminate the need for fabricating physical prototypes, and to reduce cost and time for developing new products. A virtual prototyping seeks to create a virtual environment where the development of a new model can be flexible as well as rapid, and experiments can be carried out effectively concerning kinematics, dynamics, and control aspects of the model. This paper addresses the virtual environment used for virtual prototyping of a passenger vehicle. It has been developed using the dVISE environment that provides such useful features as actions, events, sounds, and light features. A vehicle model including features, functions, and behaviors is constructed by employing an object-oriented paradigm and contains detailed information about a real-size vehicle. The human model is also implemented not only for visual and reach evaluations of the developed vehicle model, but also for behavioral visualization during a crash test. For the real time driving simulation, a neural network model is incorporated into the virtual environment. The cases of passing bumps with a vehicle are discussed in order to demonstrate the applicability of a set of developed models.

Key Words: Virtual Prototyping, Virtual Environment, Vehicle System, Occupant Model, Object Modeling Paradigm, Neural Network

1. Introduction

Nowadays, simulation techniques have an important role in reducing the development time of a new passenger vehicle model. As the most important decisions are already determined in the prototype producing stage, the design and verification of prototypes through simulations is essential. However, the conventional simulation systems have provided a designer neither with physical experiences nor with methodologies to check and visualize potential problems, prior to physical prototypes(Ye and Lin, 1997). In addition, CAD systems typically provide means to define and visualize geometries of 3D objects, but have limited capability of evaluating the operation and function of assembled parts(Coomans and Oxman, 1996). The virtual prototyping techniques have been introduced to eliminate the need for physical prototyping of a model, and to reduce cost and time for its manufacture. Often physical prototypes have limitations in accuracy of geometry, use of special materials, size of manufacturable parts, and cost. As the virtual prototyping techniques enable to simulate prototypes on computer using the virtual reality technique after creating CAD models, the concept of passenger vehicles can be initially analyzed and designed, and the features as well as the functions of prototypes can be easily evaluated, which were

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difficult to be identified(Hoffmann, 1996). For these reasons, virtual prototyping has become very important to the automotive industry. The automotive companies are trying to test-drive entire vehicles in the computer, running them through a full range of maneuvers, under various driving conditions. They even use the computer to simulate human driver response. Our suggested model can be considered as an equivalent to the current state the art.

To achieve the assessment of visual fields and reaches, implementation of virtual models can reduce the burden of modification of physical models. The assessment is possible as the various simulations are conducted by using a human model. The reach and posture assessment is carried out to verify the disposition of control devices by setting the human model into a virtual passenger vehicle(Kingsley et al., 1981). The interior structure can be adjusted as result of testing driver's view field at a certain position using an occupant model. To test the driver's response to a real crash is dangerous as well as costly. With an occupant model, however, the driver's postures and view field trajectories in a crash can be observed through animation.

The real time response to the road data should be essential to increase the reality of a driving situation. The dynamic analysis of a passenger vehicle is also demanded for the accuracy of simulations because the interaction between road and tires affects the position and the orientation (Turpin and Evans, 1995). But the real-time dynamic analysis requires a vast amount of computer memory and computational time. As one of the approaches to deal with these problems, neural networks have been introduced to the vehicle dynamic model(Ghazizadeh et al. 1996). Rivals et al. (1994) used recurrent network instead of multilayered perceptions, and simulated data to train the neural network vehicle model. Grabarek et al. (1994) presented a simulation of human behavior with the help of artificial neural networks. According to these research works, the problems associated with a real-time simulation can be coped with off-line dynamic analysis and the real-time data representation using neural network models. Use of the proposed approach enables us complete simulation up to tens or hundreds times faster than conventional numerical calculation. Using the neural network in virtual dynamic driving simulation makes real-time simulations possible in an economic way. Without a neural network, the real-time simulation can hardly be performed for such complicated dynamic system as a vehicle with an ordinary commercial computing power.

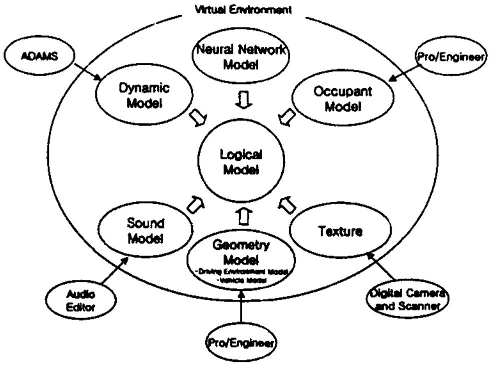


Fig. 1 Schematic diagram of virtual environment

This paper addresses the virtual environment for virtual prototyping of a passenger vehicle. The vehicle and environment models including features, functions, and behaviors are constructed by employing an object-oriented paradigm and contain the detailed information about a real-size vehicle and real driving environment. The human model is introduced not only for visual and reach evaluations of the vehicle model, but also for its behavioral visualization during a crash test. For real-time driving simulation, a neural network model is incorporated into the virtual environment which describes the dynamic behavior of the vehicle. The models developed are applied to the cases of passing bumps to demonstrate their applicability.

2. Virtual Environment Architecture

The realistic environment is required to implement virtual prototyping of passenger vehicles.

Figure 1 depicts the schematic diagram of the structure of a virtual environment exploited in this research. As in Fig. 1, the virtual environment includes important relative models such as a human model, a sound model, graphic models of passenger vehicles, a driving environment, and a dynamic model of a vehicle. Through interaction of these models with logical models defined in dVISE(Division Ltd. , 1996), the variety of the virtual prototyping simulation can be completed in a virtual environment. The tools used for developing these models are Pro/Engineer (Parametric Technology Corporation, 1997), GEBOD(Cheng et al., 1994), ATB(Obergefell et al., 1988), ADAMS(Mechanical Dynamic Inc. , 1994), a digital camera and scanner, and an audio editor. Geometry features needed for the vehicle and the circumference are developed with Pro/ Engineer. Each feature maps a texture created by using a digital camera and scanner to improve visual effects. For the dynamic simulation, ADAMS is used to obtain dynamic analysis data related to specific driving conditions. In addition, to simulate behaviors of human body in a crash event, data associated with a human model are obtained with GEBOD, and then used for the dynamic analysis under ATB.

In dVISE, details can be added to or removed from an assembly in view of graphical aspect as its distance from the viewer decreases or increases. The program creates multiple levels of detail (LOD), each of which is valid for a particular range of viewing distance, and switches among them. dVISE was used to design the virtual environment as well as the car model. It can automatically execute LOD in virtual environment to obtain the most suitable frame rate at each scene. As far as vehicle dynamics is concerned, however, the same dynamic model was used in various tests.

Figure 2 shows the graphic user interface (GUI) for the virtual environment developed under dVISE, which integrates all related models and conducts the various simulations. Texture mapping and other graphical advantages are explored as improved means to display scalar and vector quantities with interactive frame rates. The car model designed by using Pro/ENGINEER has 39 Mbytes of file size. What is important to graphic models is the number of polygons included in the model. As for this model, 23, 964 polygons were used so as to have a frame rate of over 15 frames/sec for realistic graphical representation(Chang et al. , 2000).

With this GUI, the visualization of simulation process and its results in three-dimensional space is easily realized. It is used to gain deeper insight of the dynamic behavior of the vehicle and various assessments of a human model.

3. Object Modeling for Passenger Vehicle and Driving Environment

3.1 Passenger vehicle model

A passenger vehicle model is designed by using an object-oriented paradigm which provides significant advantages over the conventional analysis and design approaches. The conventional approach is based on the procedure-oriented method and is a way to use global variables generated according to the functional deployment, after the real world problems are analyzed based upon the functional aspect, with this approach, it is therefore, difficult to recognize the relationships between processes when the variables representing the characteristic of a system are adjusted. On the other hand, an object-oriented approach enables to establish the order of thinking process, and to separate design activities. This approach defines classes and relationships among them. A class describes a set of objects having similar characteristics, attributes and behaviors. Therefore, this approach models the real word directly so that the whole system can be easily realized corresponding to changes of parameters involved in classes.

This study employs, as shown in Fig. 3, the class diagram of unified modeling language (UML). The UML describes the static structure of a passenger vehicle by classes and relationships among them. There are inheritance, association, multiplicity, and aggregation defining relationships between classes. Inheritance is the relationship between a class and its one or more

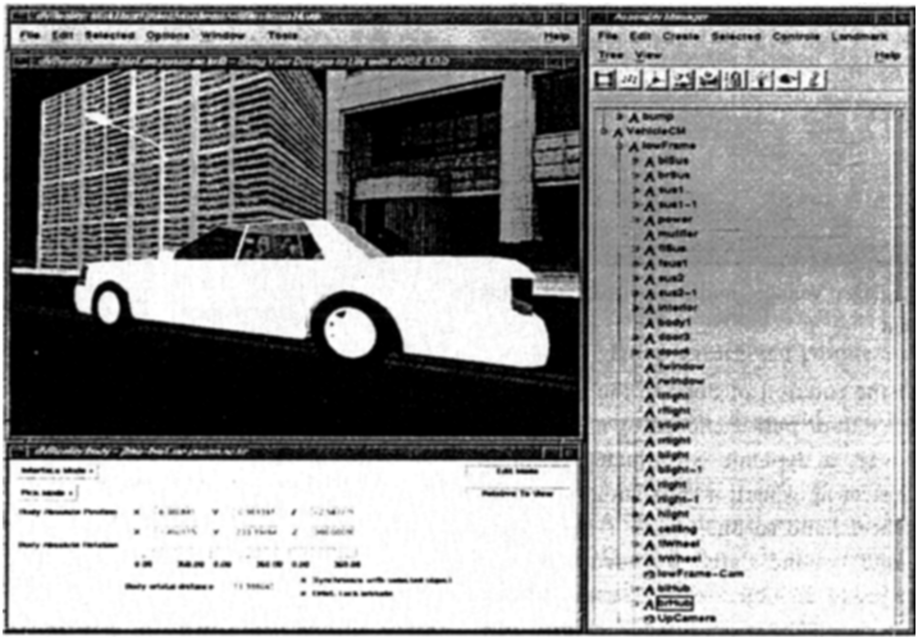


Fig. 2 Graphic user interface for virtual environment

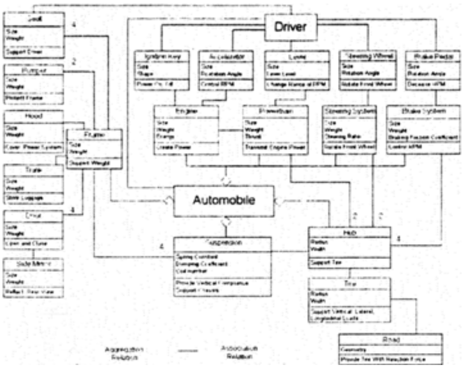


Fig. 3 Object model of passenger vehicle

refined versions. Association describes the logical link between two or more objects.

Multiplicity specifies how many instances of one class may relate to a single instance of an associated class. Aggregation is a strong form of association in which an aggregate object is made of several components. A passenger vehicle is described by aggregations which consist of a frame, an engine, a powertrain, a steering system, and hubs. In turn, a frame has associated with seats, a bumper, hubs, a trunk, doors, and side mirrors. Association defines the relation between a driver and control devices: ignition key, an accelerator, a lever, a steering wheel, and a brake pedal.

The geometry and structure of a passenger vehicle are designed using a CAD system, Pro/Engineer, according to the designed object model. The graphic objects of a vehicle are directly converted for the virtual environment. Conversion data are optimized in the virtual environment, and also the position and the orientation of the object are assigned to virtual prototyping. A dynamic coordinate system is added to desired position in order to assign a specific motion to the created objects. The motion of parts, which belong to the low hierarchy, is dependent on that of parts in a higher hierarchy. To deal with unexpected motions, constraints are assigned to objects which require specific motions. As an example, Fig. 4 illustrates a vehicle with an opened door. A dynamic coordinate system is added to the rotation axis of a door, and constraints are imposed to prevent occurrence of the exception of rotation axis. Parts such as a door window and a side mirror in a lower hierarchy are moved ac-

Fig. 4 Passenger vehicle model in virtual environment

cording to the rotation of door in the high hierarchy when a door pull is clicked by a mouse. In the same way, a dynamic coordinate system is added to a steering wheel, a lever, an accelerator, a brake, wheels, and so on.

Light and sound are included in the characteristics of an object which occurs events. Light effect should be given to such objects as a headlight, an indoor light, and a direction light. Material component and light type are defined to give a light effect. For example, material component is changed brightly and spotlight is radiated when the button is pushed to turn on indoor light. In case of a headlight, light effect is achieved as its material component is changed regularly and repeatedly. Sound is used to increase the reality of motion of an object. Sound effect is created according to the events such as horning, opening and closing of a door, ignition, driving. For example, the sound of a horn can be heard with visual effect when the button is pushed on a steering wheel.

3.2 Driving environment model

As shown in Fig. 5, the driving environment is composed of artificial environment objects, such as loads, buildings, signposts, and natural environment objects including trees and mountains. These environment objects require a large amount of polygons and material information. In order to enhance the reality of environment with less number of polygons, the texture mapping method is employed as an image source of real world which is captured with a digital camera. Hardware load rendering can be also reduced in real time. Perspective effects, lens distortion, and obstacles are eliminated through image transformation and filtering process. Multi-layer resolutions of the mapping image are structured according to distances from a point of view, and then image has been generated in 2^n pixels. The scale, the position, and the orientation of each environment component can be manipulated. Various driving environments are developed and implemented in virtual environment. Figure 6 shows one of the developed driving environments consisting of 100 textures, 30,000 meshes, and 200 objects.

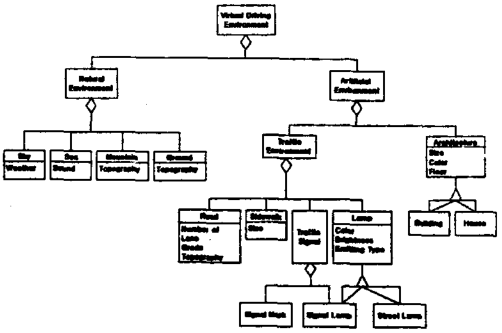


Fig. 5 Class hierarchy of driving environment

4. Human Model

A human model is developed to perform the assessment of view field and reach, and the crash simulation of an occupant model in a newly designed vehicle model. Two kinds of human models are employed. One of them is provided in dVISE for assessment of view field and reach. The geometry and the other model are created for crash simulation using GEBOD. GEBOD has capabilities of generating a data file of a dummy, which consists of 15 or 17 body components and has the same biomechanical characteristics in the impact response as a human body. To develop an occupant model used for the crash simulation by executing GEBOD, the desired geometric data of human model is obtained and then transferred to the CAD tool for a three-dimensional graphic human model, and conveyed to the ATB program for analysis of human behavior during the crash

Fig. 6 Graphic model of driving environment

Fig. 7 Driver's reach and posture assessments

test as well. An occupant model is completed in the virtual environment by integrating these two models: a graphic human model and a formulated behavior model.

4.1 Assessment of view field and reach

A human model is used to carry out the assessment of view field and reach in a new vehicle model. The view field can be evaluated by either moving a view point of the occupant model seated in the vehicle, or by creating a view frustrum which provides a possible range of a driver's view. The reach assessment is completed by evaluating such control devices as a handle, a lever, an accelerator and a brake pedal placed within an envelope of hands and feet. In another way, the assessment can be achieved through a driver's postures obtained from inverse kinematics, as a hand is placed at a steering wheel or a lever; a foot on an accelerator or a brake pedal. Figure 7 shows a driver's reach envelope representing the accessible range of the right hand. The disposition of control devices can be adjusted according to the assessment results.

4.2 Occupant simulation for a crash

To investigate a driver's response to a crash, a test can be conducted in the virtual environment instead of the real crash. This approach saves time and cost. And it increases the driving reality when applied to a driving simulator. A general analysis program of a driver during the crash lacks graphic effects, so the movement of view point is constrained. The change of visual field must be obtained at a crash to provide reality in virtual experience.

The dynamic data of an occupant are acquired by using ATB while the geometric data are done by GEBOD. Both dynamic and geometric data are linked to the object model and, then graphic presentations at various points of view are achieved in a virtual environment. As a passenger vehicle crashes against the barrier, an appropriate sound effect is generated and an animation of the occupant is performed. Figure 8 shows continuous postures of a driver at 0, 80, 160 ms after the vehicle crashes the barrier at 10 km/h of speed. Changes of the driver postures are obvious at various view points and motions of the parts of the dummy can be shown separately.

It is possible to provide a crash effect in a certain occupant position when view point is fixed to the eye of the human model. As these crash conditions are assigned, the vehicle and the environment are coordinated relatively. Virtual experience of a crash provides high reality in building up with HMD(Head Mounted Display) and sound effect devices. Under the condition of 10 km/h of crash speed, Fig. 9 illustrates consequent sight changes of an occupant of 187 cm in height on an assistant seat.

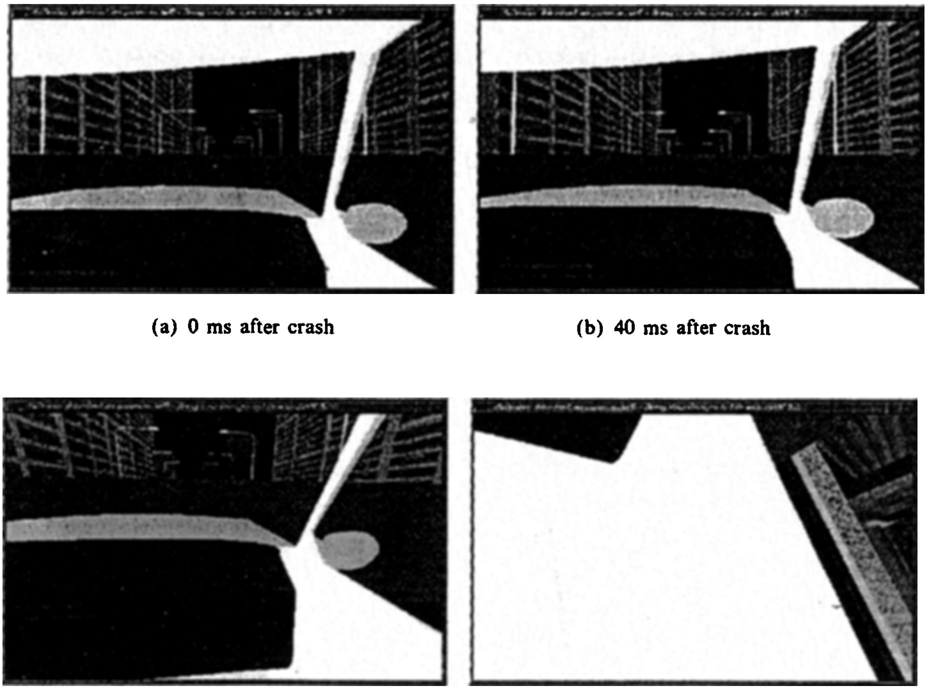
5. Real-Time Driving Simulation

Response to terrain data in virtual world must be performed in real time to increase driving reality. For this purpose, both real-time recognition of terrain data and interaction between tire and terrain are required(Rumbaugh et al., 1997). An accurate simulation is demanded because the interaction between the two affects the position and the orientation of a vehicle. To deal with this demand, the virtual driving simulation is indispensable for a real-time dynamic analysis. In the virtual environment, dynamic driving motion of a vehicle has an influence on the high reality. But the dynamic analysis that enables physical models to produce desired simulation usually requires considerable computational time. This paper introduces the neural network method, which creates physically realistic simulation in virtual driving environment based on the information provided by ADAMS. Using the neural network in virtual driving simulation, weighting factor of the neural network are automatically trained by off-line to simulate the vehicle dynamics of the physical vehicle model. Training a vehicle is quite unlike recording captured data, since the network observes isolated examples of state transitions rather than complete motion trajectories. By generalizing from sparse examples presented to it, a trained network can emulate a variety of continuous simulations that have never been actually analyzed by ADAMS. In case that a vehicle passes a bump, the real-time diving simulation is performed by using the suggested method.

Fig. 8 Driver response after crash

5.1 Dynamic modeling of a passenger vehicle

The vehicle system modeled has 15 degrees of



(a) 0 ms after crash

(b) 40 ms after crash

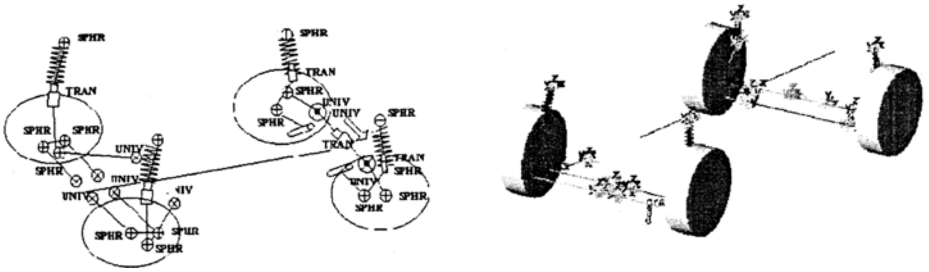
(c) 80 ms after crash

(d) 120 ms after crash

Fig. 9 Change of passenger's view field

Table 1 Mass and inertia moment

No.	Body	Mass(kg)	Inertia moment(kg·m^2)		
			Ixx	Iyy	Izz
1	Chassis	1492	437.404	2499.011	2612.43
2	Hub_fr	15	2.6	2.6	5.0
3	Hub_fl	15	2.6	2.6	5.0
4	Hub_rr	15	2.6	2.6	5.0
5	Hub_rl	15	2.6	2.6	5.0
6	Piston_rod_fr	16.72	0.001	0.001	0.001
7	Piston_rod_fl	16.72	0.001	0.001	0.001
8	Piston_rod_rr	16.72	0.001	0.001	0.001
9	Piston_rod_rl	16.72	0.001	0.001	0.001
10	Steering_rack	5	1.0	1.0	1.0
11	Control arm rlf	1.231	0.05876	0.0001	0.05876
12	Control arm rrf	1.231	0.05876	0.0001	0.05876
13	Control arm rr	1.231	0.05876	0.0001	0.05876
14	Control arm rl	1.231	0.05876	0.0001	0.05876
15	Control arm fr	1.764	0.01695	0.0001	0.01695
16	Control arm fl	1.764	0.01695	0.0001	0.01695
17	Wheel fr	15	2.0	2.0	2.5
18	Wheel fl	15	2.0	2.0	2.5
19	Wheel rr	15	2.0	2.0	2.5
20	Wheel rl	15	2.0	2.0	2.5
21	Tie rod fr	1	1.0	1.0	1.0
22	Tie rod fl	1	1.0	1.0	1.0
23	Tension bar rr	1	1.0	1.0	1.0
24	Tension bar rl	1	1.0	1.0	1.0



(a) (b)

Fig. 10 Simplified passenger vehicle model

freedom (DOF) and is composed of four wheels and a chassis which consists of total 24 bodies. The states of their connection and resulting ADAMS model are illustrated in Fig. 10. The name of each body and its mechanical properties are defined in Table 1. The suspension systems are McPherson type and independent quadralink suspension at the front and the rear wheels, re-

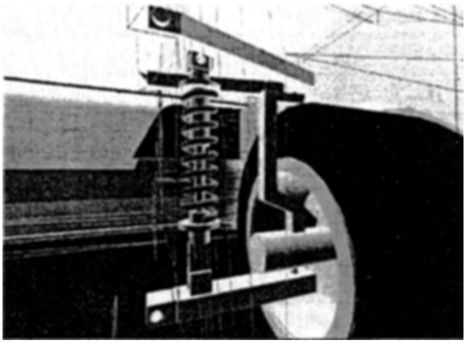


Fig. 11 Rear suspension in the virtual environment

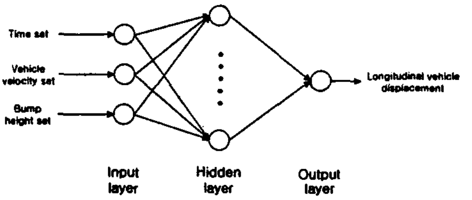


Fig. 12 Neural network for vehicle bump simulation

spectively. All these characteristics are incorporated into ADAMS for building a dynamic model of the vehicle system(Han et al., 2000).

The front and rear suspensions have a nonlinear effect that the spring constant increases sharply when its deformation is out of a specific range. The lengths of the front and the rear suspensions are 0.43 and 0.52 m, respectively at the static equilibrium position. In Fig. 11, the rear suspension in the virtual environment is shown.

5.2 Neural network model for passing bump

To simulate a vehicle passing a bump, the contact areas between tires and a bump should be recognized by the collision event manager embedded in the virtual environment. The dynamic analysis data based on a velocity and a bumper shape is animated in real time, which are represented as the backpropagation neural network (BPN) model. This model describes a dynamic behavior of passenger vehicle.

The neural network predicts motion trajectories of vehicle according to the given initial states, the velocity and the bump height. After training procedure, a neural network not only learns the vehicle dynamics along the trained trajectories, but also generalizes similar trajectories. The training data for the neural network have been obtained from the analysis program, ADAMS.

The BPN model developed here consists of many computational elements, called neurons, to correspond to their biological counterparts, operating in parallel and connecting by links with variable weights. These weights are adapted during backpropagation algorithm, by exhibiting input-output pairs in neural network structure. Figure 12 shows the construction of a four-layer neural network used to obtain vehicle chassis's longitudinal displacement during the bump passing simulation. Inputs to the network are initial velocity, bump height, and instant time. The procedure for generating the randomized training input data consists of two steps. In the first step, the lower and the upper bounds on the input variables are defined. Within these limits, a sample set is randomly obtained. Two limits are determined by considering the values of each variable that is likely to occur in the simulation of a particular driving scenario. Parameter of bump height ranges from 0.05 to 0.18 m. In the second step, an input data set of size n from k input variables is formed. There are three inputs for the simulation of passing a bump. Regarding the number of training input data needed for generalization, Ahmad suggests that the input size n in the order of $k^{2/3}$ random patterns is sufficient for a network to learn high degree of generality (Fausset, 1994). Therefore, a sample size of $n=90$ is used.

Once the network learning is completed, its generalization power is evaluated by performing the comparison of the actual output displacement and the desired one for the given initial velocity and bump height. Figures 13(a) and (b) compare neural network output data with real data, in cases of passing 0.1 m of bump height with 16 km/h of velocity and 0.16 m with 20 km/h, respectively. The square data curve is the desired output while the circle data curve is the neural network output. Small errors are obtained according to these curves, therefore, use of the neural network model pays its cost for the real-

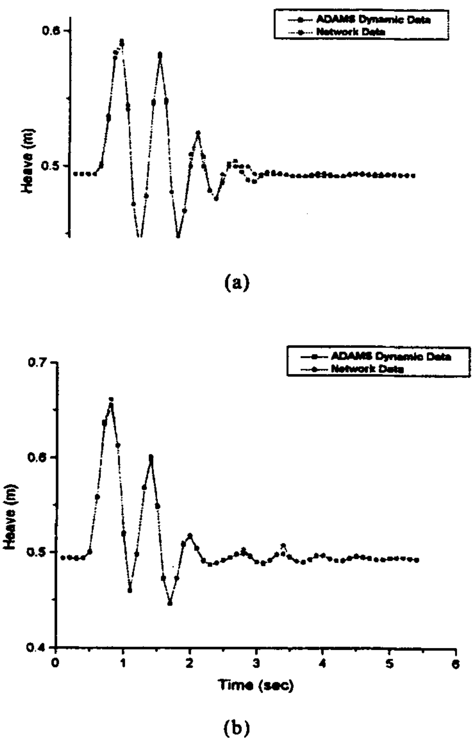


Fig. 13 Comparison of trajectories for training and reference data

time simulation. Use of the proposed approach enables us to complete simulation up to tens or hundreds times faster than the conventional numerical calculation. Using the neural network in virtual dynamic driving simulation makes real-time simulations possible in an economic way, otherwise enormous time or cost should be invested. Without a neural network, the real-time simulation can hardly be performed for such complicated dynamic system as a vehicle with an ordinary commercial computing power.

6. Conclusions

This paper presents the virtual environment for virtual prototyping of passenger vehicles developed under dVISE. All models, a passenger vehicle model, a surrounding environment, and a human model, are represented by employing the object-oriented approach which provides capability of an open scheme in designing software. The geometric data of the object model is created using the CAD tool, and is optimized to the environment for virtual prototyping. Such characteristics as the material, texture, light and sound are also added to the object to increase environmental reality.

With the virtual environment developed, various simulations can be conducted and a specific part of the vehicle can be manipulated for its evaluation. The disposition of control devices in a designed interior is evaluated through the view field and reach assessment. According to this assesment, the interior structure would be adjusted to complete optimization. Also, the real-time simulation techniques, employing neural network models, are implemented to simulate the dynamic behavior of a passenger vehicle. The numerical analysis program, ADAMS, generated the training data for the neural network. This neural network model leads to a successful real-time simulation of vehicle passing bumps.

Acknowledgements

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