SARA CAR DRIVING SIMULATOR: AN AMBITIOUS RESEARCH AND DEVELOPMENT TOOL

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ABSTRACT

This paper describes the objectives and main features of the French car driving simulator for research applications, called SARA project. Requested by the French Transport and Safety Research Institute (INRETS) and the two French car manufacturers (PEUGEOT S.A and RENAULT) this simulator allows:

-Safe and accurate evaluation of driver's attitude in various situations,
-Accurate traffic engineering research,
-Engineering evaluation of vehicle design.

This simulator is a technological state of the art design, as far as it incorporates :

-A specific motion system including a 6 DOF motion platform on top of a large X-Y linear displacement system and a specific vibration device,

-A wide field of view visual system including a 180° front field of view and rear view mirror scene displays. This system is based on a Computer Image Generator and a collimated display system,

-A specific software and database development center allowing the preparation of real time experiments and analysis of their results.

ABOUT THE AUTHORS

Michel LACROIX is the Project Engineer of the SARA car driving simulator at THOMSON-CSF, Département Simulateurs, France. Since joining THOMSON-CSF in 1973, he as been responsible for the development of control loading systems, motion systems and display systems. He holds an engineering degree from the Institut National des Sciences Appliquées de Lyon (FRANCE).

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Pierre GAURIAT is Research Director at the Computer Research Center of the French Transport and Safety Institut (INRETS, Institut National de REcherche sur les Transports et leur Sécurité). He is currently the SARA Project Manager. He received his diploma from the French Aeronautics High School in 1969. In his previous activity, he has been involved in computer graphics.

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INTRODUCTION

Operator-in-the-loop simulation has been widely used in research and development in aeronautics, as well as for training in a number of highly technical fields. Along with recent developments in computer science (CPU performance and the generation of synthetic images), it has provided the automotive industry with such tools as, for example, the simulators of VTI in Sweden, and Daimler-Benz in Germany.

In '87, French Government Agencies and car manufacturers decided to combine their efforts into a national project for a car driving simulator. Technical feasibility studies were undertaken in '87 and '88; in '89 the French Transport and Safety Research Institute (INRETS) and the two French car manufacturers PEUGEOT S.A. and RENAULT started cooperation to attain the financial and material capabilities needed to conduct such a high technology project, and to bring together work forces from different origins and of multiple experiences in a common development team.

The Simulator Division of THOMSON-CSF was chosen as the contractor for the design and manufacture of the simulator. The three partners, INRETS, PSA and RENAULT, agreed to undertake several specific parts, among which the real-time vehicle dynamic model.

GOALS AND STAKES

The purpose of the SARA Project is to build an advanced car driving simulator sophisticated enough to be used as a research tool on driver behaviour by laboratories and government agencies, and also as an engineering tool by car manufacturers during the design of a new car. This equipment should help gather skills, and should act as a mainspring for research in the field of vehicle development as well as road safety.

Since car safety is a major concern for French researchers and car manufacturers, the design and operation of a full-task simulator is a real need.

Challenges

Design of the car driving simulator will require specific research and development requiring various disciplinary approaches: mechanical engineering, mathematical models, ergonomics, acoustics, applied experimental psychology, computer science, etc.

It should be noted that the complexity of dynamic simulation of ground vehicle motion is far greater than those required to represent aircraft motion.

It has become apparent that car driving simulators have higher demands in general performance terms than aircraft simulators, for example response time is shorter and the simulation cycle time will be typically of the order of ten milliseconds.

The scientific goals are threefold:

1) Simulator Design: the vehicle application can be addressed by modern techniques, but it will be necessary to improve the latter in certain specific areas (acceleration and visual cue generation),

2) Integration Of Knowledge Of The Industrial And Scientific Partners: this is not a minor

challenge, and it also imposes upon the partners the problem of confidentiality of their own results. Consensus must be reached on the modularity of the model as a whole, and on some specific modules, such as tyre road contact. It will illustrate French know-how on the subject, while every partner will retain the possibility of using its own solutions,

3) Simulation With Respect To Driver Behaviour: the studies necessary to validate the experiments undertaken on the simulator will rather provide fundamental study of human behaviour than a mere statistical description.

For the automotive industry, the goals are twofold:

1) Simulator Design: a whole set of techniques, methods or knowledge will have to be collected and formalised. In addition to being necessary for the design of the facility, they *will prove useful beyond this field.* PSA *and* RENAULT will undertake mathematical models for vehicle dynamic behaviour in cooperation with one another and with a tyre specialist,

2) Simulator Use: it will be a sophisticated laboratory associated with road trials; it will reduce the costs and the duration of development, a noticeable improvement for the future evolution of vehicles in European research programmes and industrial projects.

Examples

At the international level and in the field of automotive and driver studies, we can mention two designs which seem to be good examples of such car driving simulators.

The VTI car driving simulator (Vag och Trafic Institut) with a three degree of freedom motion base: the main criticism which can be levelled at this good simulator is its inability to depict a very complex road scene. In other respects the simulation, although limited, is of perfectly adequate quality for the studies involved. In 1990 and 1991 this success led the VTI to design and build a new simulator based on the same principles.

The Daimler-Benz simulator (DB research center in Berlin) better known than the above: the general architecture is comparable to aeronautic simulators with a 6 DOF motion system. The design is both remarkable and impressive. However, the quality of operating and image simulation systems reveals the improvements that could be made in the ability of the motion base to reproduce certain violent transient phenomena which occur when driving at limits or in an emergency situation.

Research Areas

Three research fields are concerned:

- Vehicle,
- Road environment,
- Driver behaviour in a realistic driving situation.

The simulator is a research tool well adapted to a "system" approach. It will facilitate program and research themes combining the above three fields.

1) Vehicle Design - This important goal has enabled definition of the basic level of simulator performance (motion system, mathematical model validity and the quality of visual restitution).

The simulator will be used as a test laboratory in order to complement the traditional tools of the manufacturers. Its main use, however, will be the development of new architectures and new solutions. The final adjustment of the vehicle which requires a very subtle appreciation of car behaviour and consequently accurate modelling of both car and tyre effects is not envisaged at the moment.

The simulator will host the following studies, which need both a complex tool and the "decision" of a human driver:

- When in the first step of new car conception, the comparison of various technological solutions, and the validation of technical choices,

- At road behaviour study level, a "credible" numerical model for professional testers will help develop parametric studies. It will also help study the evolution of parameters inaccessible when in real situations,

- For the design of new vehicle architectures involving active subsystems (e.g. active suspension), the simulator will be used, for example, for the analysis of the consequences of the architecture on the primary safety of the vehicle. Qualification studies will be undertaken on the simulator, with, according to the user's wishes, the mathematical model of the subsystem or the actual subsystem,

- Closely related to the latter, the study of modern instrument panels, although possible with part-task simulators, will nonetheless use the advanced simulator when it becomes necessary to assess the impact of new driving aids on driving behaviour.

2) Research On Driving Tasks And Active Safety- Without a full-task simulator, several studies are too complex or dangerous to be conducted on the road. For example, an integrated tool with the possibility of simulating a realistic driving situation is necessary for research on driving behaviour:

- Emergency driving manoeuvres,

- New electronic driving aids and the capacity to minimize the effects of loss of concentration,

- Effects of tiredness, alcohol and drugs on the driver,

- Typology of behaviour and driving *strategies, impact on energy consumption in* given situations,

- Detection of objective indications and of parameters constituting a feeling of safety.

3) Road Engineering For Road Safety Administration And Research Laboratories - The advanced car driving simulator can be used to conduct road design and road sign legibility research, at three levels :

- Fundamental research, related to the aforementioned studies, for which the driver's sensations are critical,

- Applied research: the simulator will *increasingly be used for studies on visibility* and marking, especially in borderline situations (night, atmospheric disturbance, etc.), with the purpose of designing new tools and improving placement methodologies,

- "In the field" studies: important road programmes will need "in situ" studies on the simulator for specific problems. For example, the modification of geometrical parameters will be undertaken after the study of the behaviour of several drivers on several vehicles (light vehicle, trucks, convoys, etc.).

Obviously standard road or highway projects do not need this advanced facility. But design of critical sites and improvement of important black spots will be demonstrated and tested on simulator before building, with positive effects on time and cost.

Let us point out the advantages of the car driving simulator as opposed to more traditional investigation tools, in particular experimentation on track or road:

- The situation studied can be reproduced,

- An experimental scenario can be reproduced with possible variations,

- Tests can be conducted on a model of the vehicle without having to actually build it,

- A degree of freedom exists in the modification of those variables which cannot be easily *managed during actual tests, and parametrical* analysis is easier,

- It is possible to analise dangerous situations safely.

SIMULATOR DESIGN

The SARA car driving simulator is a technological state of the art design, as far as it incorporates:

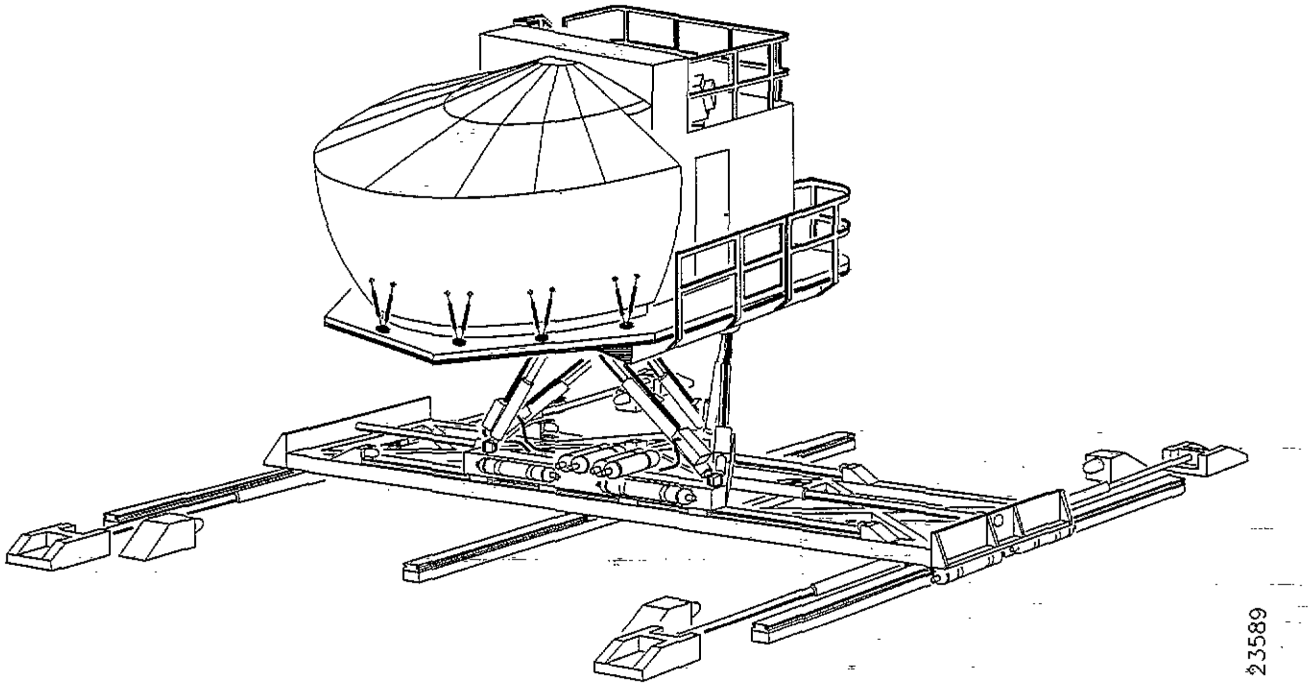


Figure 1 - Car Driving Simulator Motion System

- A specific motion system including a 6 DOF motion platform, a large X-Y linear displacement system and a vibration device.

- A wide field of view visual system including a 180° front field of view and rear view mirror scene displays. This system is based on a Computer Image Generator and a collimated display system.

- A specific software and database development center allowing the preparation of real time experiments and the analysis of their results.

MOTION SYSTEM

The motion system shall provide large amplitude and low frequency motions in lateral, longitudinal, pitch, roll and yaw as well as low amplitude and high frequency motions in the six degrees of freedom. This is achieved by the use of a 6 DOF synergistic motion system on top of a large X-Y motion system and a specific vibration device fitted under the car structure. A physical layout of the motion system is shown in Figure 1.

Performance Requirements

The motion system must generate a sufficient level of motion cueing fidelity to evoke natural driver response behaviour. According to the level of cueing fidelity sought, motion system performance requirements can be established.

The approach taken to establish the performance needed is to simulate the 6 DOF motion system on top of the large X-Y linear displacement system, and to drive it with accelerations that have been recorded in a real vehicle with linear and angular accelerometers placed under the driver's seat for several manoeuvres such as lane change, step steering, emergency braking. For the fidelity factor sought i.e. the ratio of recovered acceleration to drive acceleration, the required motion system excursion, velocity and acceleration envelopes are obtained.

Because the motion system has limited horizontal excursions, long-term lateral and longitudinal accelerations cannot be maintained using only linear motions and, cabin tilting must be added. Lateral or longitudinal motions reproduce with no lag the start of the

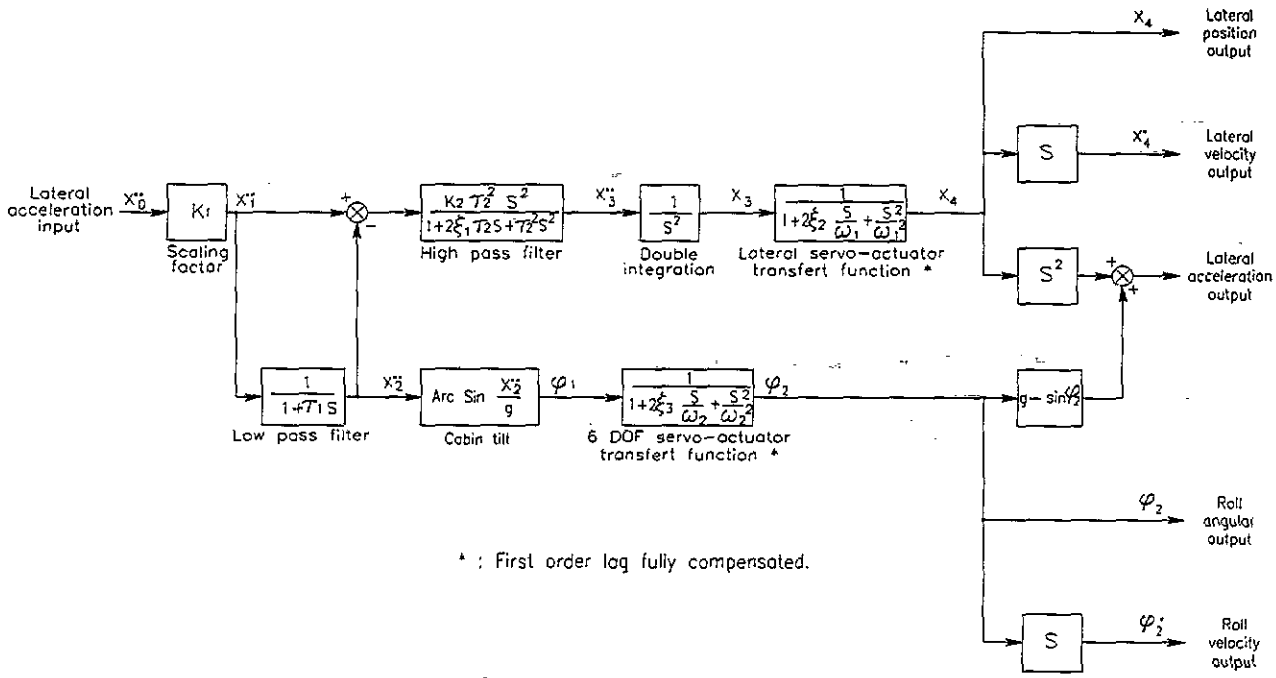


Figure 2 - Lateral Motion Block Diagram

acceleration which is maintained by roll or pitch cabin tilt.

The system modelling block diagram for the lateral motion is given in Figure 2. Low pass and high pass filters are used to separate long and short term accelerations(low and high frequency terms). The lateral acceleration input is first filtered with a first-order low pass filter to obtain the longterm acceleration for calculation of the roll tilt angle. After multiplication by the 6 DOF servo actuator transfer function, the roll tilt angle of the cabin is obtained and the resulting simulated lateral acceleration due to gravity is computed.

The filtered lateral acceleration used to compute the roll tilt angle is subtracted from the lateral acceleration input and the result is filtered with a second order high pass filter and integrated twice to get the lateral position of the cabin. After multiplication by the large X-Y motion system transfer function, the lateral position is obtained and differentiated twice to get the simulated lateral acceleration.

Simulated lateral accelerations from the large X-Y motion system and the 6 DOF motion system are summed and compared to the lateral acceleration input. Gain and time constants of high pass and low pass filters are adjusted to get a smooth acceleration transition between the large X-Y motion system and the 6 DOF motion system and to maintain the tilt rates below the human threshold of perception.

Using the simulation model, motion system excursion, velocity and acceleration envelopes have been computed for lane change, step steering and emergency braking. Results of the simulation for a lane change are given in Figure 3. This shows a fidelity factor of 0.7.

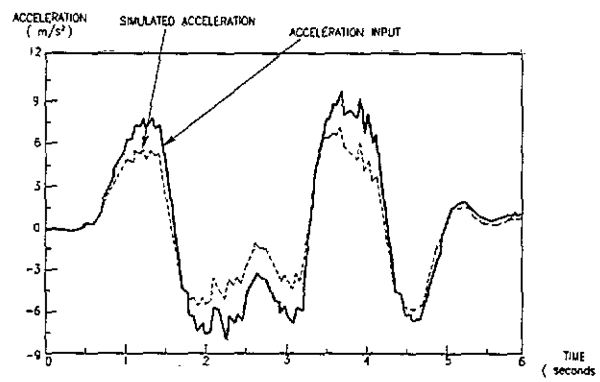


Figure 3 - Simulated Lane Change Response

Large X-Y Motion System

The main difficulty is to meet large excursions, high velocities and low acceleration noise levels. The acceleration noise mainly comes from drive vibrations transmitted by the mechanical structure and turnaround bumps due to Coulomb friction and backlash in the drive and carriage systems. For the drive system, the use of hydraulic or electric motors with rack and pinions or wire cables has been eliminated since they lead to friction, backlash and vibration problems. The use of a direct linear acting device has been preferred with the choice of either a linear electric motor or a hydraulic actuator. The latter has been selected because it is a proven technology, used on 6 DOF motion systems for flight simulators.

The hydraulic actuators are double-acting equal area cylinders fitted with hydrostatic bearings for zero Coulomb friction. One actuator is used for the lateral motion drive and two identical actuators working in parallel are used for the longitudinal motion drive.

The guidance system consists of a lateral (Y) carriage and a longitudinal (X) carriage sliding on one another. In order to get a coulomb friction as low as possible, the X-Y motion system is guided by means of hydrostatic bearings.

The lateral carriage is equipped with three double-acting hydrostatic bearings that are fitted under the triangular base of the 6 DOF motion platform to support vertical compression and extension forces, and with two identical hydrostatic bearings that are fitted on one side of the base to support longitudinal forces.

The longitudinal carriage beam structure is equipped with 6 double-acting hydrostatic bearings to support vertical forces and 3 double-acting hydrostatic bearings to support lateral forces.

6 DOF Motion System

The 6 DOF motion system is identical to the system used on commercial aircraft flight simulators except for the geometry which has been modified to get ± 30 degrees usable angular excursion in pitch and roll. This system incorporates hydrostatic actuators, ultrasonic position transducers and a digital servocontrol system with force feedback.

Vibration Platform

The vibration platform has 6 degrees of freedom and it is used to reproduce vibrations from 3 Hz to 30 Hz. This platform is of the same design as those used on helicopter flight simulators and it can generate accelerations up to ± 1.5 g. The vibration platform is fitted inside the motion platform frame and it supports only the car structure. This solution avoids vibration of the display system at high frequency.

DISPLAY SYSTEM

The display system comprises a collimated wide angle display system for the view through the front windows of the car and a real image projection system for the rear view mirrors. The complete display system is contained in a light-tight enclosure and its general arrangement is shown in Figure 4.

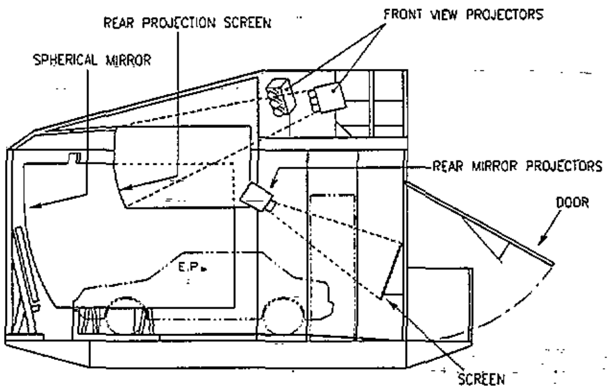


Figure 4 - Display System General Arrangement

Collimated Wide Angle Display System

The system gives a continuous panoramic field of view of 180° horizontal by 40° vertical and has a resolution better than 3.0 arc minutes.

The visual scene displayed is produced by three CGI channels. Each channel drives a high brightness CRT projector mounted above the car shell on a rigid gantry. The projectors produce images on a spherical projection screen fitted above the car's front windows. The images of each visual channel are carefully aligned and matched to produce a continuous scene on the projection screen which is viewed by the driver via a wrap-around spherical concave mirror.

The mirror is so positioned in relation to the screen that a collimated image can be seen by the driver. In comparison with a real image projected onto a dome screen, the collimated image recreates the time needed for the eyes to accommodate from an object at infinity to the dashboard, and it also gives the driver the feeling of being immersed in the visual scene.

Rear Mirrors Display System

This system comprises a flat screen located behind the car and two projectors mounted above the car structure and under the rigid gantry that supports the three projectors of the collimated display system. The two projectors correspond to left hand and center rear view mirrors. The projectors used are commercial video projectors since edge matching and high brightness are not needed.

COMPUTING CENTER

The simulator is designed to perform studies on driver reactions, and on vehicle and road environment designs. These studies require multiple experiments that must be prepared, performed and analysed.

The preparation phase consists of the assembly of the different data necessary to define the experiment i.e. the vehicle dynamic model, the visual database, the scenario, and the informations to be recorded during the real-time execution of the experiment. Once the experiment has been performed on the real-time simulator, the recordings must be checked and analysed.

Because the preparation and analysis phases take a certain amount of time to be performed, and because three different users can be working simultaneously, the simulation center houses two different systems as shown in Figure 5 :

- The real-time simulator dedicated to the execution of experiments. This system can only be used by one user at a time,

- The support system dedicated to the preparation and analysis phases where the three different users can work simultaneously using a secure software environment.

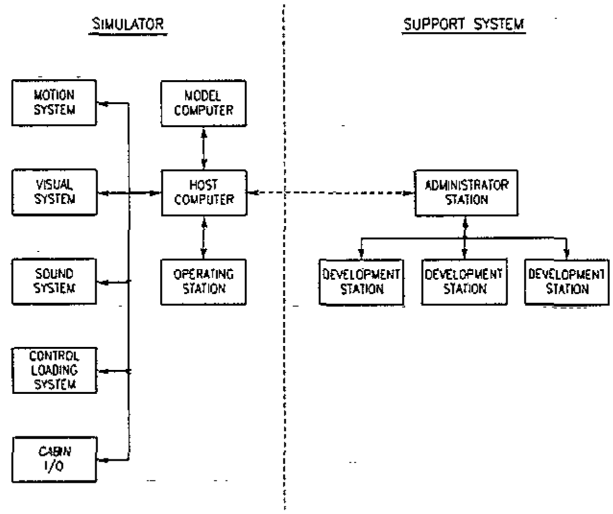


Figure 5- Computing Center Architecture

Exchange of data between the two systems is operated through the control of the administrator by using a magneto-optical disc device.

Real-Time Computing Center

One of the most important features of the SARA simulator is to be a research simulator. This means that its structure must be sufficiently evolutive to allow future upgradings.

From this point of view the computing facility comprises a host computer dedicated to the standard simulation software (considered as the basic system software insofar as it should not support major evolutions) and an associated computer, called "model computer", housing the vehicle dynamic model software (considered as the applicative software insofar as it will support continuous improvements).

1) Host Computer. Its functions are:

- The real-time monitoring of the simulator. This function is dedicated to the management of the different software modules running on the computer, and to the correct synchronization of subsystems such as visual system, motion system, control loading system, model computer and operating station during the simulation cycle. It also manages the input/output data flow between the host computer and the subsystems,

- The simulation of the environment that generates all the data required by each subsystem. It provides the visual system with the visibility conditions and the position of the observer and of the different moving objects. It also provides the sound system with the sound parameters corresponding to the environment and the driver's actions. One of the main simulation functions of the host computer lies in the motion system control software which takes into account a large range of parameters (driver's actions, vehicle characteristics, driving database informations), in order to compute those commands most adapted to reaching the actual motion cue. This control software can be adapted according to each manoeuver characteristic by simply modulating the control of each degree of freedom available on the motion system. The modulation algorithm is predefined by the user when preparing the experiment,

- The scenario management that manages the experiment conditions (vehicle paths, meteorological conditions, animations, data to be recorded) which have been set up during the experiment preparation. Note that experiment execution is controlled through the operating station where most of the information can be displayed.

2) Model Computer. This computer houses the dynamic vehicle model. It provides the host computer (through a reflective memory) with the parameters necessary to compute the complete environment and perception cues. A user-friendly Model Generator, allowing description and modelling of a vehicle with the precision needed by engineers whilst remaining acceptable for real time simulation, is used to generate the code that will be run by the model computer. This software will allow the description and the simulation of any kind of rigid or flexible constrained multibody system on which a set of complex subsystems acts. These subsystems will be real or modelled devices of any kind (mechanical, hydraulic, electric, electronic, etc.).

Support System

As discussed earlier this development facility is a multi-user device. For this reason, the system is based on a secure B1 environment. Three identical configurations are provided. They all include the software tools necessary to perform the development of the experiments and the analysis of the recordings. Main development tools are:

1) Database Creation Tool which allows the creation of the environment database used by different subsystems of the simulator. Starting from a unique model of the environment, this tool generates four distinct and coherent databases:

   - the visual database used by the image generator to compute the visual scene,

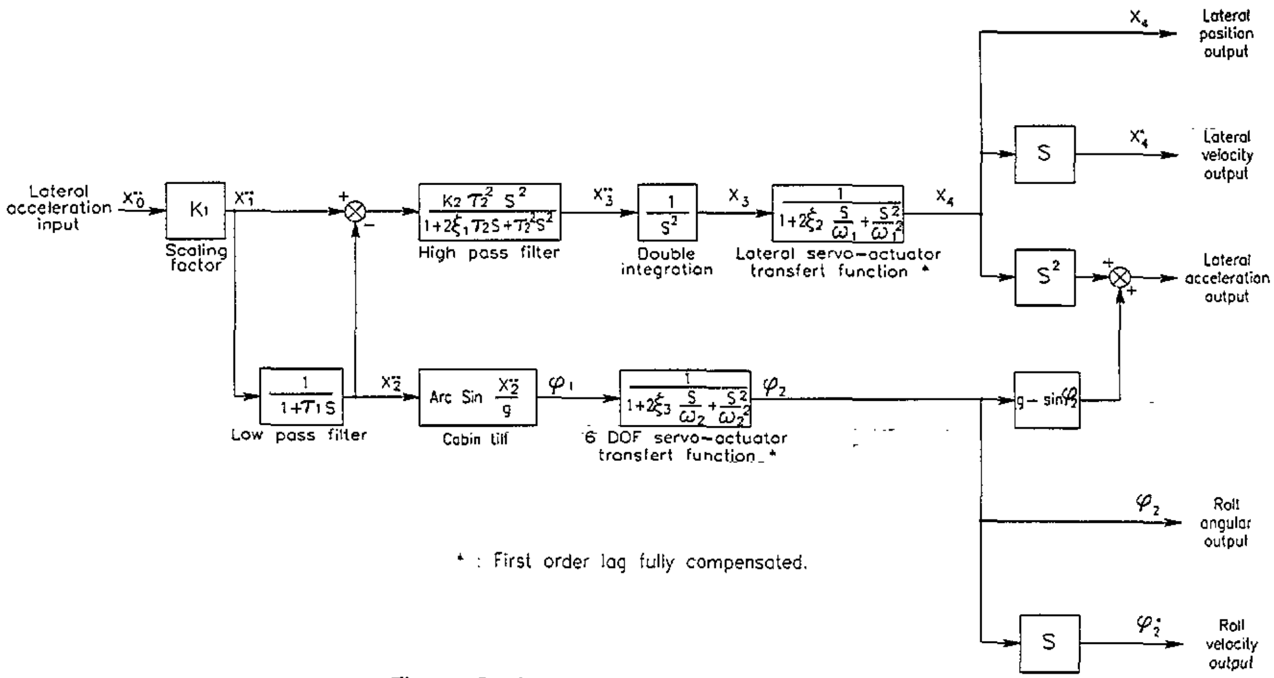
   - the sound database used by the sound system to generate the correlated noises,

   - the driving database used by the host computer to determine the data to be used by the vehicle dynamic model (charateristics of the terrain) and the motion system control software,

   - the operating station database used to display the map of the database (control of the experiment),

2) Scenario Creation/Modification Tool which defines all the events that will occur during the experiment, i.e. moving vehicle path, correlations between the moving object attitude and the environment (driver, database, etc.), animations (level crossing, lights, etc.), evolution of visibility conditions (fog, light sources, etc.), data to be recorded during the experiment, etc.,

3) Motion Control Software Tool which identifies the required algorithms to be used during the real-time experiment. It provides the user with all the information and parameters to be set up in the motion control software, in order to get the optimum response of the motion system. The adequate



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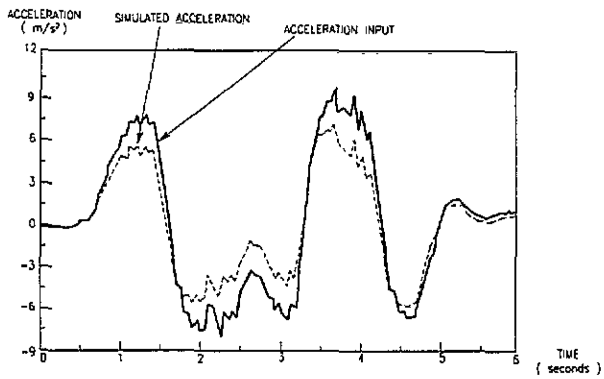

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