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An integrated framework combining a traffic simulator and a driving simulator

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Abstract

Driving simulation has been used for many years now in research, industry and training to simulate virtual driving conditions. This is largely because simulation saves engineering time and costs, and virtual situations provide an easier and safer way to carry out road and traffic safety studies. Scenarios or scenes that realistically reproduce traffic behaviour according to the traffic flow theory has been developed since the 1980s and traffic simulators are a widely used technology in the research, planning, evaluation and development of new traffic systems (for instance Intelligent Traffic Systems). The aim of this paper is to explain how providing a simulation framework based on the integration of a driving simulation engine and a traffic simulation can respond to the issues addressed by offering multi-level and multi-domain simulation models. This paper describes the integration of the driving simulator SCANER and the traffic simulator Aimsun, where the driving simulator (including visual, audio and kinaesthetic restitution) manages the simulation in the immediate driver environment and the traffic simulator manages the whole road network situation, creating a large-scale, realistic and minutely detailed virtual world.
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1. Introduction

To reduce road accidents and improve driver safety, the automotive industry has developed a great variety of new systems like Automotive Driver Assistance Systems (ADAS) including Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) systems. In this context, engineers and researchers need simulation tools in order to imagine (at the preliminary design stage), prototype, develop and validate such systems. Those systems imply a wide range of heterogeneous technologies (wireless communication, sensors and vehicle) and the simulation will have to create realistic models to represent the complexity of the environment in which they will be used.

The drivers' interaction with those systems, how they accept them and how they react in critical situations is a major subject for behavioral studies. Driving simulation is now commonly used to help answer these questions as it allows researchers to put the driver in situations that might be difficult or dangerous to recreate in the real world.

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To achieve these goals, the simulated world needs to be realistic from the perspective of both the driver and the system. This is particularly true for simulating traffic vehicles. The simulator driver sits in a real vehicle cockpit and has a visual perception of the surrounding world through synthesized images generated by computers and projected on the screens. From his point of view, "realistic" means that the vehicles in his sight line move as if they were real cars and behave as if they were driven by humans.

The simulation of a realistic traffic situation, from the perspective of the traffic simulator, has the following requirements:

1. Autonomous vehicles controlled by the traffic model move around the "human driven" vehicle in a realistic manner showing realistic kinematics and vehicle interactions.
2. Vehicles move according to the macroscopic behavior of traffic streams, especially in congested traffic patterns.
3. The traffic conditions, in some experiments, should be the same as the driver would expect to find in the real world i.e., the dynamic pattern of the traffic flow in the simulated network should closely resemble the real pattern, considering all aspects of traffic engineering, such as ITS, adaptive traffic controls and traffic management actions.

The traffic model that simulates surrounding vehicles for driving simulation from a larger traffic flow model has already been proposed for the VTI Driving simulator III (Olstam, 2005), the ARCHISIM model (Espié, 1995) and the NADS model (Bonakdarian et al., 1998). In these models, only the vehicles in a moving window around the driven vehicle are simulated. Other trials (Bang et al, 2004) have been based on integrating Aimsun traffic simulation (Barceló and Casas, 2002) with the SCANeR simulator.

In this paper we propose a new approach to integrating a multi-scale traffic model for driving simulation and by extension, a new simulation framework for ADAS and ITS studies. We present the driving simulation framework in Section 2 and the traffic simulator in Section 3. In Section 4, we detail the integrated framework including the shared description of environment and the strategies for traffic vehicle control.

2. The driving simulation framework

The driving simulation framework SCANeR™, developed by Renault and Oktal, is composed of functional modules dialoging over the network. The traffic module, in charge of the animation of the autonomous vehicles surrounding the driver, has a multi-agent architectural design (Champion et al, 1999). Each vehicle is modeled as an autonomous agent that interacts with other vehicles and the surrounding environment through perception, decision and action algorithms. Vehicle behavior can be controlled through the scenario module to provoke predefined situations in which the performance of the simulator driver will be evaluated. To achieve the complete immersion of the driver in the virtual world, the realism of the traffic vehicles behavior must fulfill certain conditions.

First of all, the dynamic of the car must be realistic, including its movement, speed and acceleration. The surrounding vehicles are perceived by the driver through the Visual module that generates synthesis images at 60 Hz. The Traffic module must then provide information at a similar refresh rate. To improve dynamic simulation of the vehicles, the architecture of the model has recently evolved to separate the virtual driver from the virtual vehicle. Now each agent has their own dynamic model, and, as a generic software interface is used, any dynamic model supported in SCANeR™ can be chosen. This means that the dynamic model of the autonomous vehicles can be the same as one driven by a human, and can thus be equipped with the same ADAS system, which allows the study of the interaction between systems.

A second aspect of the realism that the traffic model must provide for driving simulation is the behavior of the autonomous vehicle. This should react as if it were driven by a human. The behavior of the autonomous agent is organized in perception, cognition and actuation subsystems while the perception of the environment includes the road network and the surrounding vehicles. This perception uses the topological description of the road offered by the RoadXML format and the evaluation of Cartesian distances. The cognition subsystem is subdivided according to the driving task decision level: strategic, tactical and operational (Michon, 1985). The actuation subsystem provides all the inputs for driving the dynamic model. Each behavior can be customized through pseudo psychological parameters such as overtaking risk, speed limitation observation, safety time and signalization respect. Using these parameters, classes of behavior and individual elements can be created through normative principles to improve the global realism of the traffic simulation by offering various kinds of behavior (Lacroix, 2009).

The SCANER™ traffic model as we describe it, is very well adapted to the needs of driving simulation and provides an adapted degree of realism for the simulation of the vehicles surrounding the driver. In point of fact it is not designed to be realistic at a higher level, regarding for example, the traffic flows. Extending the qualification of "micro" for traffic model where the vehicles exist as entities, the model could be qualified as "nano" corresponding to the fact that the movements are smooth and continuous and are computed from a dynamic model.

3. The traffic simulator

The traffic simulator Aimsun is developed and marketed by TSS-Transport Simulation Systems, Aimsun is an open and extensible traffic modeling application, uniquely capable of fusing static, dynamic and hybrid approaches within a single environment.

Aimsun has applications of any scale and complexity, whether the project at hand is safety analysis, urban traffic management or evaluating public transport systems, and is capable of running simulation models of entire cities much faster than real time. The software supports static and dynamic equilibrium traffic assignment, matrix adjustments, network traversals, detection layout optimization and dynamic simulations. Aimsun has interfaces to most demand modeling, signal optimization and adaptive control tools along with the Legion pedestrian simulator. With regard to modeling vehicle movements at a microscopic level, Aimsun simulations imply models for the drivers' car-following and lane-changing behavior.

3.1. The car-following model in Aimsun

The car-following model implemented in Aimsun is based on the well known Gipps model (Gipps, 1981). This model pertains to the "safety distance" or "collision avoidance" types of model. Models of this type aim at specifying a safe following distance and then adapt the driver's behavior in order to maintain it. In practice, the Gipps model assumes that the following driver chooses their speed so that they can maintain the minimum distance whenever the leader brakes at its maximum deceleration rate.

Thus, according to the Gipps model, the speed V(n, t+T) attained by a vehicle at a given instant (t + T) (in which the delay T is the "apparent" driver's reaction time (Gipps, 1981) is given by:

$$V_a(n,t+T) = V(n,t) + 2.5a(n)T\left(1 - \frac{V(n,t)}{V^*(n)}\right)\sqrt{0.025 + \frac{V(n,t)}{V^*(n)}} \tag{1}$$

$$V_b(n,t+T) = d(n)T + \sqrt{d(n)^2 T^2 - d(n)\left[2\{x(n-1,t) - s(n-1) - x(n,t)\} - V(n,t)T - \frac{V(n-1,t)^2}{d'(n-1)}\right]} \tag{2}$$

$$V(n,t+T) = \min\left\{V_a(n,t+T), V_b(n,t+T)\right\} \tag{3}$$

To compute the speed and Gap we use the following formula:
$$s(n,t+T) = s(n,t) + (V(n-1,t) - V(n,t)) \times T \tag{4}$$

where:
- d(n) (< 0) is the maximum deceleration desired by vehicle n
- x(n,t) is position of vehicle n at time t
- x(n-1,t) is position of preceding vehicle (n-1) at time t
- s(n-1) is the effective length of vehicle (n-1) including a safety margin
- d'(n-1) is an estimation of vehicle (n-1) desired deceleration.
- T is the reaction time.
- V*(n) is the target speed of vehicle n, computed as Max{Position Speed Limit * Speed Acceptance of vehicle n, Maximum Speed of vehicle n}.

3.2. The lane-changing model in Aimsun

The lane-changing model implemented in Aimsun is an adaptation of the model provided in (Gipps, 1986). Essentially, the decision to change lane is modeled as a process, analyzing the necessity of the lane change e.g., to follow the vehicle's determined route, the desirability of the lane change e.g., to maintain the desired speed when the lead vehicle is slower, and the feasibility of the lane change itself (depending on the location of the vehicle in the road network). Once the need to change lanes has been ascertained for a certain vehicle, the model checks whether the vehicle will find the desired characteristics in the destination lane, e.g., if a vehicle wants to change lanes to attain its desired speed, the model checks whether traffic conditions in the destination lane will allow this. Again, for further details, see (Aimsun, 2010).

The need to change lanes usually involves another decision: changing lanes usually means using the existing gap between two vehicles on the destination lane so a driver must decide whether this gap is acceptable. The gap acceptance model is then used to reproduce this additional decision. Again, further details are available in (Aimsun, 2010).

4. The integrated framework

4.1. The principle

In previous integrations, the traffic simulator replaced the driving simulator traffic model completely, and the environment was manually recreated in both applications (Bang et al., 2004). This approach raised a certain number of concerns. Manual creation lead to errors in the network description, and thus generated inconsistencies. The direct use of traffic simulator output caused visual defects for the driver: during lane change the trajectory was not smooth and continuous; the refresh rate of the traffic model was too low compared with that of the visual module and the human driver reaction, which resulted in jerkiness and collisions. The new approach that we have proposed and developed is to use the Aimsun micro traffic model and the SCANeR™ traffic model in parallel. In this approach, Aimsun is in charge of the traffic simulation across the whole network while SCANeR™ controls the driver's immediate driving environment. The two applications exchange information in real time during the simulation. We have also used a common description of the road network based on a new standard exchange format.

4.2. Road network

To integrate the driving simulator and the traffic simulator, the first need was to share a common description of the environment. In SCANeR the description of the road network is based on the RoadXML format which is the outcome of several years of research and development by INRETS, PSA and RENAULT (Chaplier, 2010). It has been developed to answer all the road description needs for driving simulators by offering a multi-layer description of the environment and fast data access for real-time applications. The main layers of information available are:
- Topological: the element's location and connections with the rest of the network
- Logical: the element's significance in a road environment;
- Physical: the element's properties (road surface or obstacles);
- Visual: the element's 3D representation.

Already used in a broad variety of training and research driving simulators, the RoadXML format has been opened as a freely usable format in 2009 and proposed to the simulation community as a standard for exchanging database and facilitating the operability between applications. The format has been chosen as a reference for a common description of the road network between Aimsun and SCANeR.

Figure 1 Road network exchange between SCANeR and Aimsun

Using the open source parser available, the RoadXML format import has been developed in Aimsun. A SCANeR road network can be imported in Aimsun and the user can then prepare a micro-traffic simulation by adding the following items:

1. Traffic demand: this can be defined by:
    a. OD Matrices: An OD Matrix contains all the trips that will be generated in a network for a particular vehicle type and in a defined time period. The cell (i,j) of an OD Matrix contains the number of vehicles going from centroid i to centroid j.
    b. Traffic State: A traffic state contains all the input flows that will be generated in a network for a particular vehicle type and a defined time period as well as the turning proportions at nodes (when more than one turning is possible from a section).
2. Traffic Control: For each intersection the model should define all signal groups with their movements, including the yield signs (Stop, Yield or Right Turn on Red), and then the definition of the control plan (uncontrolled, pre-timed, actuated or connected with an adaptive control system)
3. Public Transport: Defines the public transport route with a set of public transport stops (where the service time is defined) and the time tables of each public transport line.

4.3. The driving simulator window

Using a similar approach to the ARCHISIM model (Espié, 1995), NADS model (Bonakdarian et al, 1998) or the VTI Driving simulator III (Olstam, 2005), we take up the notion of a local window for the simulation of surrounding vehicles. In this window, the SCANeR™ "nano" traffic model controls the vehicles as opposed to the rest of the network where the traffic is managed by the Aimsun micro model. This window will follow the driven vehicle ensuring that vehicles around the driver are always animated according to the level of realism needed for the driving simulation. The nano traffic window can also be positioned at a fixed point of the database to enable local event-driven scenarios e.g, at an intersection where a vehicle does not respect the signalization, provoking an emergency reaction from the simulator driver.

When a vehicle from the micro-traffic model enters the window, it is dynamically created in the nano traffic model and all of the main characteristics of the vehicle are transmitted: vehicle type, size, target speed, etc. The vehicle exists in the whole driving simulation framework, including visual and sound restitution. Inside the window, the vehicle is controlled by the nano traffic model but still exists in the micro traffic model. When the vehicle exits the window, it is deleted from the nano traffic and control is restored to the micro traffic model.

This solution raises an issue for the nano traffic vehicle at the boundary of the window: because it is the end of their world, they don't perceive the next vehicles and their behavior might not reflect (virtual) reality. To solve this problem we have added the notion of an intermediate zone where the vehicle exists in the nano traffic model but is

controlled by the micro traffic model. The vehicles at the frontier can then perceive the other vehicles and adapt their reaction.
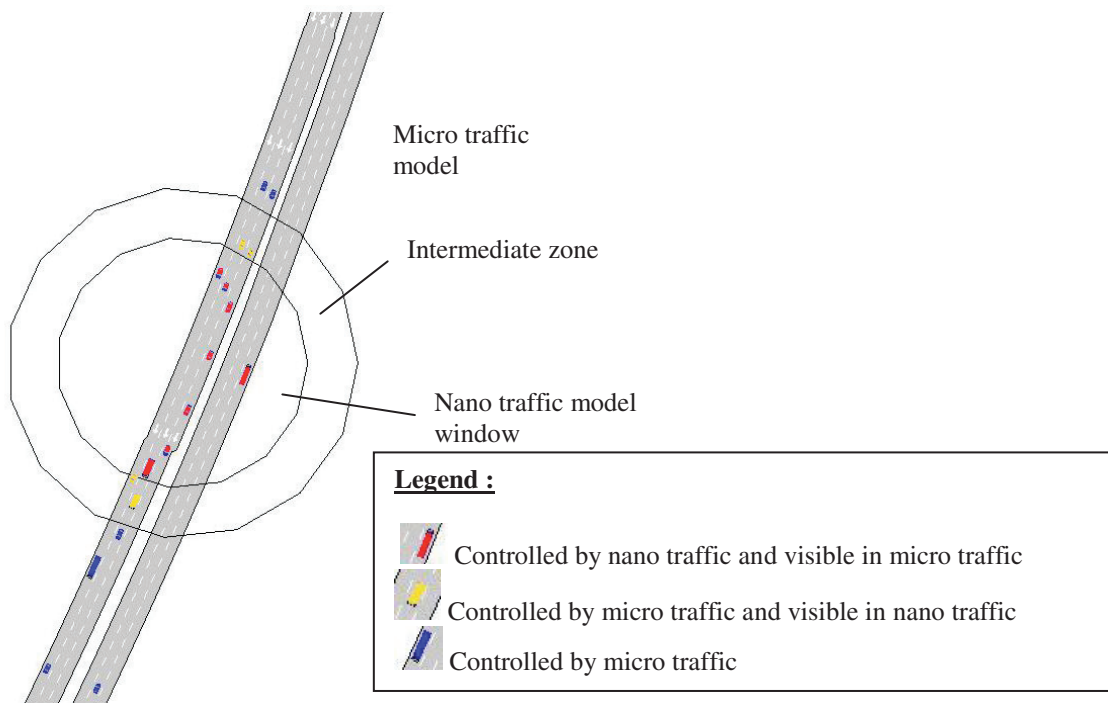

Figure 2: Nano traffic model window and intermediate zone

4.4. The integrated framework

In Aimsun every simulation step (the minimum is 0.1 second) updates the position of each vehicle according to the behavioral models (car-following and lane-changing) with a pre-calculated order determined by the configuration of the network topology. The integrated framework introduces a variation of work flow defined at each simulation step where the behavioral models are applied to the vehicles present in the micro traffic and intermediate zones. Meanwhile, the vehicles present in the nano traffic zone and the position and speed of each vehicle is updated according to the data exchanged with the driving simulator.

4.5. ADAS development and validation

SCANeR™ simulation engine provide multi-domain and multi-level models: vehicle dynamic, virtual driver, virtual sensors, nano traffic. All those models can be improved or customize using a dedicated SDK.

In Aimsun, using the tool Micro SDK, is possible to overwrite the behavioral models (car-following and lane changing model), and allowing to include the ADAS systems that modifies the driver behavior, for instance the Automatic Cruise Control.

The ADAS systems can thus be implemented in the integrated simulation framework at different level depending on the goal of the study.

For development purpose, those systems can be integrated in the dynamic vehicle model in SCANeR™ to implement functions like FCW (Front Collision Warning) or LDW (Lane Departure Warning) that take control of

the car in case of emergency situation. These systems will use sensor models that deliver an electronic perception of the surrounding traffic vehicles.

When considering acceptance and reaction of the human driver, prototypes of real HMI (Human Machine Interface) can be integrated in the simulator cockpit and evaluated in different kind of predefined situation. The integrated framework can then provide detailed information about the environment like relative position of the surrounding vehicles, traffic density on the roads, and occurrence of specific events (accident, traffic jam, etc.)

Outputs of the different models can be collected and processed to analyze and evaluate the results of the simulation, including in Aimsun is possible to get trajectory data (and all aggregated data derived from it) from the vehicle driven by the driving simulator.

5. Conclusion

In this paper we have presented a new integrated framework that combines driving simulation and traffic simulation. This framework allows the driver to drive in a simulator with a local traffic situation managed by a nano traffic model, that is realistic for the driver, and that also provides a realistic global traffic situation in terms of flow and density. Considering the ADAS field of application, the simulation can thus provide local and global information on vehicles and traffic situation for short range sensors, like camera or radar for example, and also for long range systems like wireless communication or embedded navigation. It allows us to immerse the driver and new systems in a broad variety of traffic situations including accident, road work zones, rerouting, etc.

The integration of a multi-level traffic model raises questions about the global validity of the resulting model. The particular question of how the nano traffic window affects the micro traffic model needs to be studied in great detail. During the development we tried our hardest to guarantee the consistency of the framework, for example, when vehicles are transferred from one model, they retain most of their static and dynamic characteristics. An important point is that the result will depend on the size of the nano traffic window. A compromise needs to be found between a large window that will favour driver immersion and a small one that could provoke visual defacts, but will have less impact on the result of the micro traffic simulation. To compare the result, there is still the option of reducing the nano traffic window to zero, conserving only the intermediate zone. In this case only the micro traffic model is used.

This framework has been tested on different types of simulators and recently deployed on a full-scale simulator where there are plans to use it in traffic safety research and ADAS study.
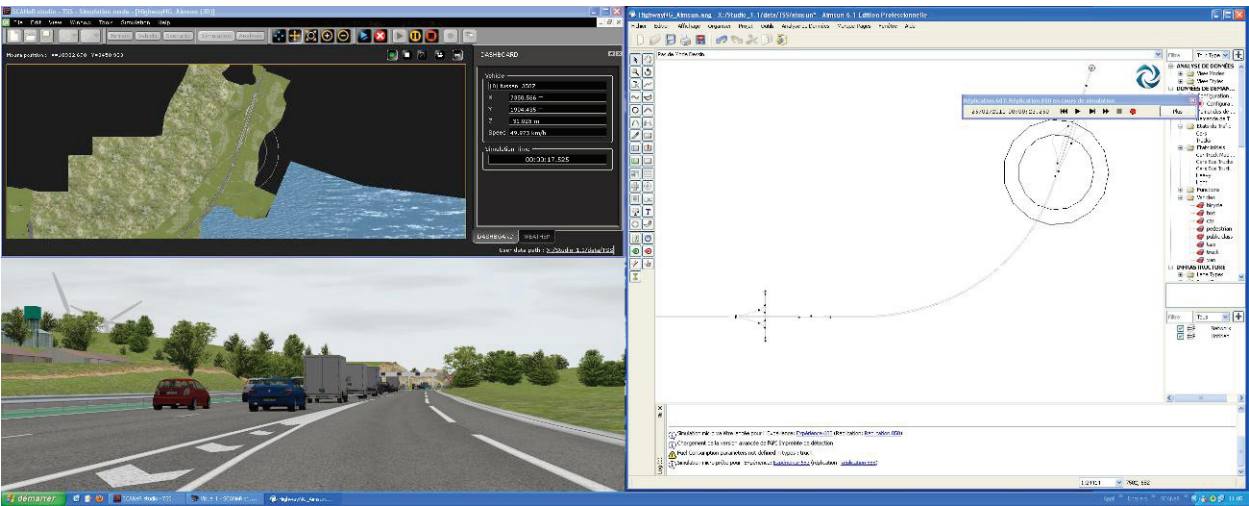

Figure 3 The SCANeR and Aimsun integrated framework

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