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DISTRIBUTED REAL-TIME VEHICLE VALIDATION

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1 ABSTRACT

Due to the increasing complexity of embedded systems and software in vehicles, the automotive industry faces an increasing need for testing and verification of components and subsystems under realistic conditions. At the same time, development cycles must be shortened for vehicle manufacturers to be competitive on the global market, and an increased amount of testing and verification must thus be performed in less time. However, simply increasing the testing volume can be prohibitively costly, meaning that testing and verification processes must be made more efficient to reduce the need for more prototypes.

This paper presents a concept for distributed testing and verification of vehicles in real-time, with the aim of improving testing and verification efficiency. Through a novel combination of software tools for distributed collaborative engineering, real-time simulation, visualization, and black box simulation, the realized system makes it possible for vehicle manufacturers and their subcontractors to work more concurrently and efficiently with testing and validation. An early implementation of a system prototype is described and future development plans for the system are presented. The main software components used to build up the system are ADAMS/Car RealTime, Matlab/Simulink and a Java-based real-time visualization module originally developed for the gaming industry.

A main benefit of the concept is that different disciplines involved in the product development process can use the system to enhance the concurrency between them. Control systems and mechanical engineers can view ongoing tests in real-time and change designs, and efficiently re-simulate and influence ongoing tests in a distributed manner. Through advanced visualization of simulation results and measurement data, engineers can get a clearer view of how the system or product behaves, thereby improving the quality of the validation process.

The concept for distributed real-time simulation and visualization described in this paper will gather more information during the early stages of product development, and speed up the product development process due to its real-time nature. The fact that engineers can stay at their home office and only follow the test when needed will enhance their efficiency.

2 INTRODUCTION

Outsourcing the development of components and systems to subcontractors by manufacturers is a clear trend in the automotive industry. Consequently, the overall quality of the finished product will depend on how well automotive companies and subcontractors work together in the development processes. The lack of harmonization between not only subcontractors and the automotive company, but also between different development departments at the manufacturer causes expensive errors in the final product. Therefore, methods and tools that are easy to work with and are applicable in industry have to be developed to support the whole development process [1, 2].

The need for vehicle validation has increased during recent years, mainly due to the increasingly complex electronic control systems developed for the vehicles. Much time is spent on validation to manufacture reliable and safe systems.

To quote Vincentelli [3], "It is no wonder that more than 30% of severe malfunctions in automobiles are originated by faulty software. We need a new system science to deal with the digital abstraction and the physical world in a unified way."

This paper suggests methods and tools to reduce lead-times in the validation phases of product development (PD). It also exemplifies how we can cope with digital abstraction and the physical world.

Today's automotive companies must be able to cope with distributed product development due to the many suppliers involved in vehicle development. Dannenberg [1] estimates around 5,000 suppliers to the automotive industry today. Since suppliers and subcontractors from all over the world frequently need to be involved in the testing and verification of vehicles, developing sophisticated methods and tools for distributed validation and simulation is necessary, and to incorporate these tools and methods into the overall framework for distributed product development.

The idea with the distributed real-time simulation and visualization (DRTSV) concept is to extend the testing and verification processes, from the test tracks to the development offices of the manufacturer and subcontractors. This will result in more effective test sessions and shorter development cycles. Furthermore, connecting system modules that are mechanical, controlled or both to the DRTSV concept in a black box fashion, as suggested by Larsson et al. [8], will provide the manufacturer and subcontractors a promising conceptual tool to support the PD process. The black-box mode enables suppliers to protect their own knowledge, while still sharing the response of their systems as executable models.

By using a wireless local area network (WLAN) at the test tracks, live measurement data can be sent from vehicles at the test track back to the development site of the manufacturer for analysis and visualization, in real-time if desired. Having the possibility to share and view data in real-time from the test track will significantly reduce costs and lead-times for vehicle manufacturers. Törlind [7] describes a technological framework by which car manufacturers and suppliers in northern Sweden have the possibility to transmit data in real-time from test vehicles to development facilities worldwide. By integrating this framework with the system presented here, live measurement data can be used as input for hardware-in-the-loop simulation and real-time visualization, giving the opportunity to study effects that are not directly measurable, such as the normal forces on the tires of a moving car.

Our vision is for future automotive test engineers to be able to take part in vehicle testing without being physically present at the test track, and still as involved in the tests as if they were present. To achieve this, measurement data must be transmitted in real-time to the development site, where it can be analyzed and visualized. Moreover, interpersonal communication and data exchange between local and remote engineers must be flexible and effortless. As an illustration of this vision, consider a case where the engineers wish to study the influence of a suspension module on the braking performance on ice. Using our approach, they can do so by feeding live measurement data (acceleration, position, speed) into a dynamic simulation module that calculates the normal forces on the tires. The normal forces can be visualized in real-time in a virtual reality system, e.g. as dynamically changing graphical vectors. Further, one part of the suspension simulation system can be located at a subcontractor who is using a black box simulation approach to protect the simulation model. The dynamic simulation forces on the suspension module are transmitted to the subcontractor, and the tire forces are returned. All information from the simulation module can be combined with measured data from the car on the test track and either visualized in a shared visualization system or presented as curves.

Imagine if sending measurement data directly to an expert's office, where it is visualized and analyzed in real-time, any test can be performed. The expert can follow the ongoing test through both a virtual reality 3D visualization of the vehicle, and a video from the vehicle. If the expert can speak to the test driver through an audio link, he can influence the ongoing test to better suit his needs. There is also a possibility for the remote expert to download new software directly to the vehicle through the wireless communication link. Working in this manner will reduce the overall test time and provide time for even more tests, or simply reduce the time for the test cycle. Engineers from the home office no longer have to travel to the test session they can follow the test session from their office and let the local entrepreneurs perform the tests for them. This will greatly save the automotive manufacturers and suppliers time and money.

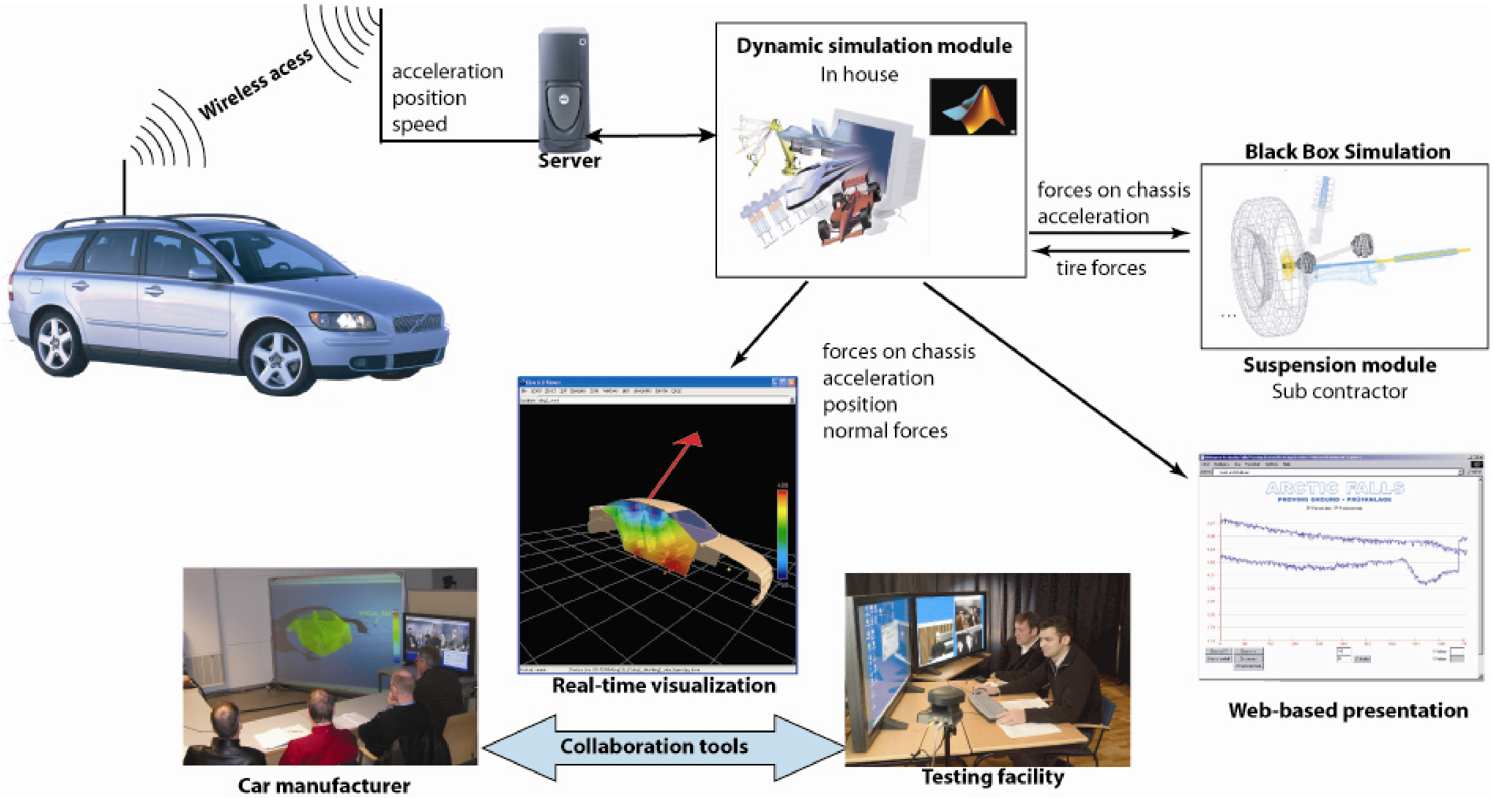

Figure 1. Real-Time simulation with hardware in the loop and black box simulation.

By using a dynamic simulation system to simulate the behavior of the vehicle, accessing difficult or even impossible data to measure is possible, e.g. force between tire and road, forces in joints, etc.

The visualization module can be set up to simultaneously present data considered interesting to many disciplines, e.g. climate, fatigue, control systems, vibration analysis, etc.

3 RELATED WORK AND BACKGROUND

The work presented in this paper builds on previous work from the Division of Computer Aided Design at Luleå University of Technology concerning distributed collaborative engineering (DCE), distributed automotive winter testing and multi-body simulation of vehicles.

Larsson et al. [8] present a system for web-based simulation where only a web browser is needed as interface to the underlying simulation core and the user can work anywhere in the world in a thin client fashion. The most evident advantage is the possibility to distribute simulation modules, or whole simulation models, from simulation experts to design experts and engineers. This distributed approach allows cooperating companies to protect company specific knowledge by distributing simulation modules of models or complete systems in a black box fashion, where certain parameters are available for modification, whereas other company sensitive parameters and structures are protected. Extending this approach to use simulation modules [9] allows for sub models to be distributed throughout the network.

By combining the above-mentioned technologies with existing technologies for remote collection of telemetric data from test objects [7], the distributed simulation can be combined with hardware-in-the-loop, HIL [11], simulations. Integrating these technologies permits new possibilities for merging simulation with hardware to be achieved. Törlind et al. [7] consider climate testing with static visualization modules, though this can be generalized to virtually any kind of testing scenario and integrated into the new dynamic visualization module.

4 THE DISTRIBUTED REAL-TIME VEHICLE VALIDATION CONCEPT

By combining Distributed Collaborative Engineering, Real-Time simulation and visualization, and black box simulation, vehicle manufacturers and their suppliers gain a very powerful PD tool for car testing. One of the main benefits of this concept is that different disciplines involved in the product development process can use the system to enhance the concurrency between them. Control system engineers and mechanical engineers can view ongoing tests in real-time and change designs, and efficiently re-simulate and influence ongoing tests in a distributed way. Through advanced visualization of simulation results and measurement data, the engineers can get a clearer view of how the system or product behaves, and thus improve the quality of the validation process.

An early prototype of a software framework for distributed real-time vehicle validation is presented in this paper. The framework is largely based on well-known software components presently used in the automotive industry, which facilitates implementation of the concept in industry. The prototype consists of input, data management, simulation and visualization components, as illustrated in Figure 2. The components have the following functionality:

- The input component sends steering, throttle and brake signals to the data management block via network link and UDP protocol.
- The data management block consists of a Matlab/Simulink [5] component that receives data from the input component, performs some necessary preprocessing, and sends it to the simulation component.
- The simulation block is an ADAMS/Car RealTime [4] component that computes the behavior of the car based on a given input and a simulation model. The result is sent back to the data management component that processes the data and transmits it over a network link to the visualization module via UDP protocol.
- The visualization component receives data such as position, velocity, forces, etc., and combines this data with a 3D model of the car for 3D visualization of the car's behavior in a virtual environment.

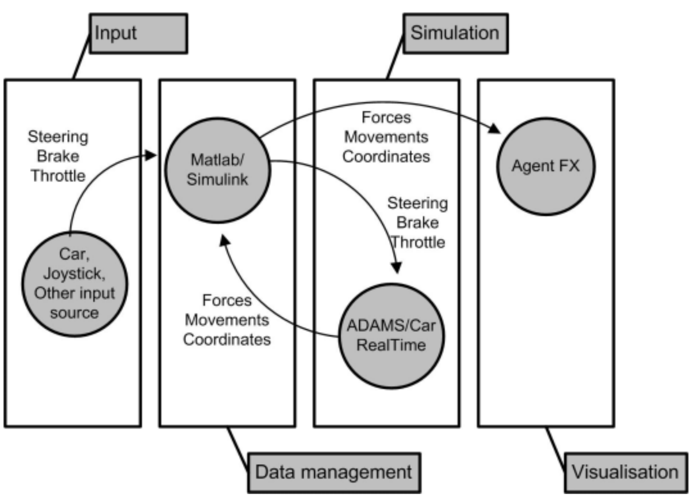

Figure 2. Early prototype system of real-time simulation and visualization.

4.1 Product Development process

The following section describes how the DRTSV concept can be used in the PD process.

As previously noted, future vehicle testing processes need to be faster and more effective, to test all new vehicle control systems. These control systems will increase in numbers and complexity in the future, meaning that the methods for testing vehicles and their control systems need to be enhanced considerably to decrease the time spent on testing [7]. One way to achieve this is to use wireless technology at the test facilities to perform concurrent validation from remote locations. What this means is that an engineer at the development office for automotive systems can concurrently work with one subsystem of the vehicle, while a test session is conducted on another vehicle subsystem. Input data to a simulation model can thus be received, in real-time, from a car at an ongoing test session.

Meanwhile, a software engineer can work with a different subsystem and receive data from the same test session. From the 3D visualization of the car and live video transmissions, they can monitor the performance of their systems. With the possibility of communicating with the test driver through an audio (and video) link, valuable information about how their systems perform can be obtained, and changed directly if necessary. Uploading software upgrades to the ECUs in test vehicles can be done from the development site when network connection to the vehicle exists. Engineers at the development site can work on new software for the vehicles' ECUs during the tests and upload them when problems are solved or when new versions are finished. According to Miucic [12], the time needed to upload new software and erase FLASH memory only takes a few seconds. Due to this fact the engineers at the development office can upload new software between test drives. The remote programming of the vehicles' embedded systems will be essential in the future distributed vehicle validation process [12].

Saving the input data from the test session into a file format readable by the simulator (e.g. in ADAMS/Car typically a driver control file, DCF) will allow more detailed simulations of problems that arise after the test is finished. By saving logged data from the car together with the DCF, the engineers can reproduce the problem and make changes to the software or design.

The concept will be useful for hardware-in-the-loop, software-in-the-loop and real-time validation during test sessions. Using the system from early product development to validation of preproduction systems at the test sessions is possible (see Figure 3).

4.2 Visualization

The use of a dynamics simulator such as ADAMS/Car RealTime allows for hard or even impossible to measure test data to be produced, e.g. tire, chassis forces.

By using a 3D engine originally developed for the gaming industry, it is possible to build extremely realistic synthetic environments. Visualization in real-time demands high graphics performance, requiring different 3D graphics engines compared to what CAE tools have to offer. Hence, the use of visualization tools from the gaming industry – considered today the technological vanguard of 3D visualization – are interesting for this application.

With the use of a Global Positioning System (GPS) and maps, it is possible to model the whole test track with trees, buildings, sunlight, shadows, etc. Modeling sunlight and its direction can be useful not only for added visual realism, but also to provide information, for instance, about why the temperature inside a coupe suddenly increased at a climate test. Another reason to want highly realistic graphics is to keep track of the environment where the vehicle is during the test.

Adding special features to the real-time visualization model will give the viewer a better and more logical overview. Vector force and moment graphics will be of use when monitoring the behavior of dynamic control systems. Vectors that visualize the normal forces on the tires provide much information about how the vehicle behaves. Changing the colors of parts when special events occur, e.g. when systems fail or when the brakes lock the wheels, gives a clear and prompt notification to the user. When the visualization model consists of many parts, a function to show or hide the parts during simulation will be useful. Using a cutting plane through the model will also enhance the viewability of the model, as well as give the possibility to visualize temperature, vibration and sound fields in the model. Color gradients in the cutting plane of the model can represent this.

Being able to save simulations in the visualization module gives the engineer a better view of how the new system will work. For example, you have saved the last simulation and will now modify the system to run a new simulation with the saved simulation as a reference. This will give the engineer direct visual confirmation of how the system behaved in a particular situation.

4.3 Implementation in industry

There are numerous areas in the PD process where the DRTSV concept will be suitable (see Figure 3). When considering a black box simulation with DRTSV, this is applicable from the development of early control systems solutions up to preproduction control systems.

The first area is prototype system development. During development, data from the actual testing can be used to simulate the behavior of the prototype system in the vehicle. The systems can be tested for early bugs and misbehaviors.

Secondly, virtual simulation allows specified systems to be tuned.

Thirdly, systems for preproduction vehicles can be tuned concurrently during test sessions.

Another area of implementation would be the distributed visualization and simulation to the suppliers. Mechanical engineers also have good usage of DRTSV, especially since mechanical systems have to function well with electronic systems and software. Using the same tool suite and methods will harmonize the work of electronic and mechanical engineers in the automotive industry [2].

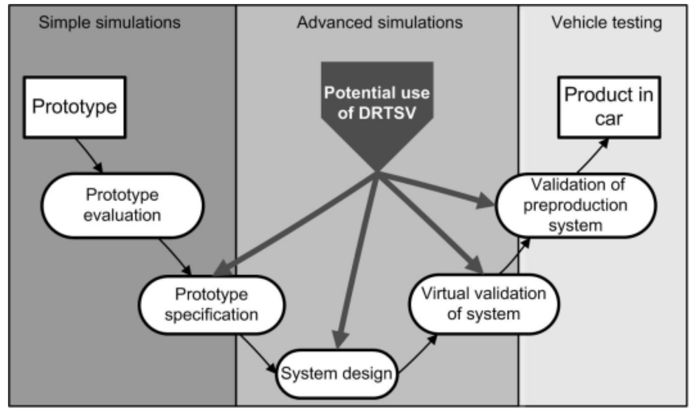

Figure 3. Potential use of DRTSV, displayed in the V-model for the development process of electronic systems and software.

5 RESULTS

The preliminary result of this work is an early prototype system based on a combination of software tools, some of which are already used in the automotive industry, mainly ADAMS/Car RealTime, Matlab/Simulink and a Java-based 3D visualization module called AgentFX.

5.1 Prototype system

A schematic model of the prototype system can be seen in Figure 2. Tested inputs to this system are a joystick and a measurement collection and transmission unit installed in an actual car, in this case a formula SAE car built by students at Luleå University of Technology. The formula car was chosen instead of a production vehicle due to the ability to perform system tests at a quicker pace and with better control of the whole system.

5.1.1 System input

The first input source used was a joystick to test the simulation and visualization part of the system. The joystick was connected to a Simulink model that sent the joysticks signals (throttle, brake and steering) via network and UDP protocol to the data management block.

A first test sent CAN-bus data from the car to the data management block. Throttle, brake and steering inputs were sent from the car while it was standing still in the laboratory. In future work, wheel speed data will be sent from the car to minimize the difference between simulated and real dynamic behavior.

5.1.2 Data management and communication

Matlab/Simulink is used as the communication interface between ADAMS/Car RealTime, the visualization tool AgentFX™ and the real-time data input from the car. The Simulink model collects input data to the real-time model from the car's CAN-bus (throttle, brake and steering). Simulink passes the data onto ADAMS solver for dynamic calculations; ADAMS then passes the results back to the Simulink model; Simulink packetizes the data needed for visualization into units suitable for network communication, and then sends it to the visualization tool AgentFX™ [5].

5.1.3 Simulation

For the last 20 years, automotive manufacturers have used multi-body simulation tools in virtual product development (VPD) to not only understand how the product will perform, but also the different phenomena that can arise. Using MBS together with other software components will give an effective tool for solving complex and multi-disciplinary problems.

The formula SAE car was modeled in ADAMS/Car and exported to ADAMS/Car RealTime. The ADAMS/Car model has 71 degrees of freedom (DOF) and the Real-Time model has 16 DOF. The ADAMS/Car RealTime model does not have linkages or bushings, and its steering system does not have parts for the steering wheel or rack. Instead, the model requires input parameters from, e.g. Kinematics and Compliance (K&C) test machine or data virtually obtained from ADAMS/Car simulations. This makes it possible to run the simulation faster than real-time [4].

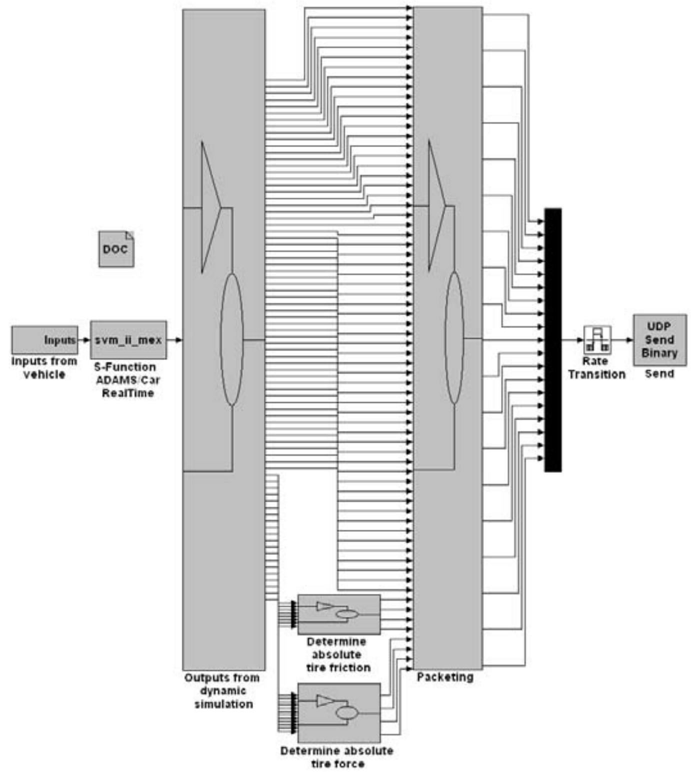

Figure 4. Matlab/Simulink model.

5.1.4 Visualization

AgentFX™, an advanced toolkit for developing interactive 3D applications and objects in real-time, is based on Java and uses the OpenGL Application Programming Interface (API).

AgentFX™ allows software development for a wide range of platforms, eliminating the need to rewrite code for different platforms. Applications are immediately ready for use on platforms such as Microsoft Windows, Apple Mac OS X, Web environments, handheld units using Pocket PC or similar, Linux and UNIX workstations such as SUN Sparc, and more.

The advantages of using this kind of software is high graphical performance and applicability in heterogeneous computing environments, since the visualization module can be executed from any computer with a Java virtual machine installed.

Currently, the car's dynamic properties, e.g. normal forces acting on the tires contact patch, vehicle speed and direction, are implemented in the visualization application. In Figure 4 the left rear wheel is displayed as red due to the exceeded absolute slippage; also note the top right hand corner of the picture displaying the absolute forces acting on the tires.

Future implementation could be different types of test information, such as temperature data displayed with a cutting plane through the body with graded colors. These different types of test information should be easily accessible through the top toolbar.

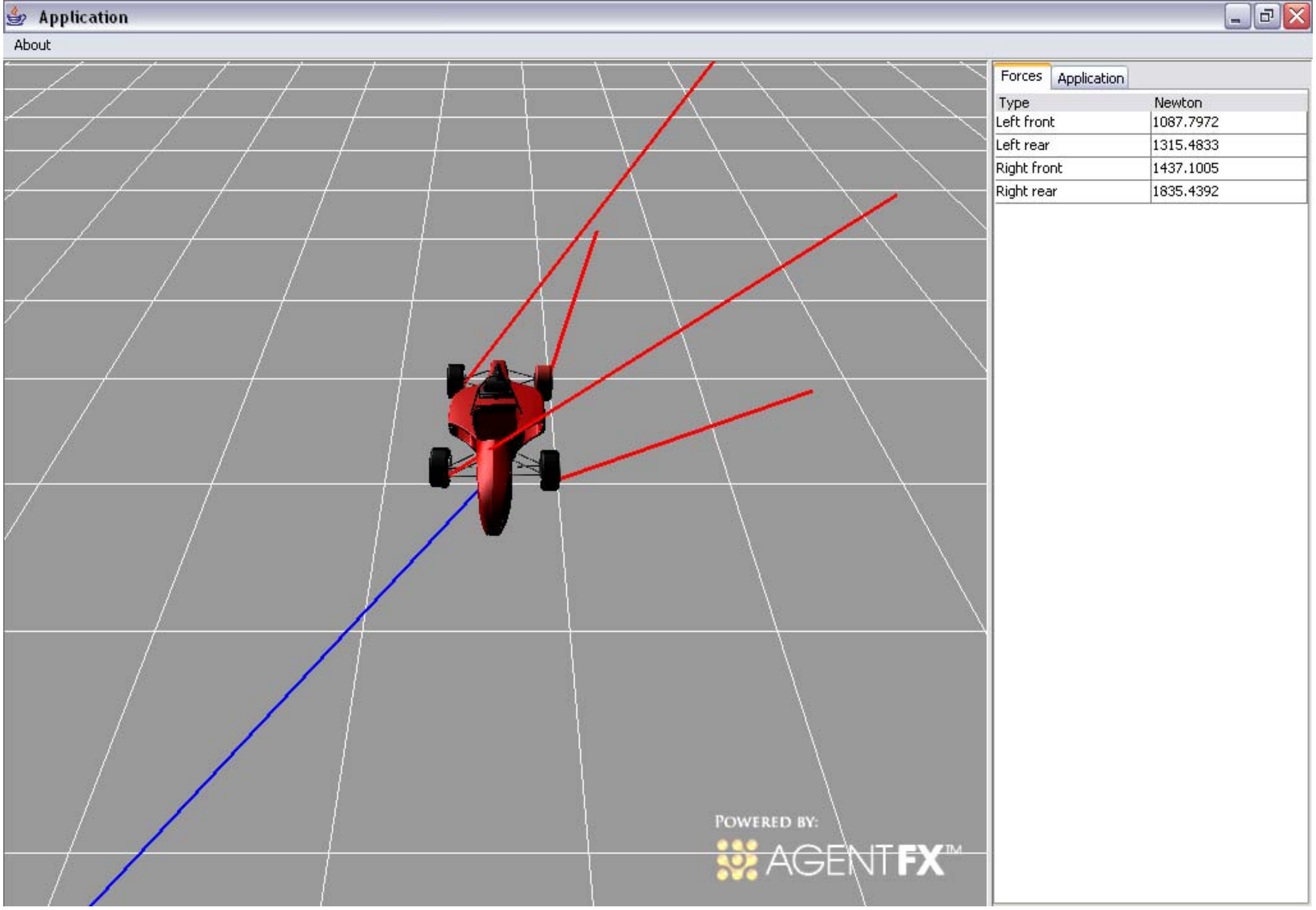

Figure 4. Visualization application with applied textures, forces and speed arrows.

6 CONCLUSION AND FUTURE WORK

Future work consists of testing the measurement data collection and communication unit installed in the formula SAE car. Real tests at a local winter test facility will be performed to validate the functionality, bandwidth requirements, and how close to real-time can the system work. Also, further work on the visualization model of the car and the virtual environment will be preformed for enhanced realism. Whether or not Matlab/Simulink and ADAMS/Car RealTime can be used for purposes other than explored in this paper will be investigated. Questions concerning data acquisition will be worked upon in parallel with another research projects. The intention of this system is for it to be eventually tested on a conventional car from the automotive industry.

During the PD process, gathering as much information as possible about the product is crucial. This information will help eliminate flaws for the next generation of the product. The concept for distributed real-time vehicle validation described in this paper will facilitate the collection of data in the early product development stages. Moreover, it will accelerate the product development process due to its real-time nature, promoting instant analysis of measurement and simulation data. The fact that highly competent engineers can to a larger extent remain at their home office and still partake in remote testing sessions will increase their productivity when it is needed and enhance their efficiency.

Recording input data from real tests will permit earlier usage of the system in the development process, e.g. concurrent engineering between supplier and automotive manufacturer or between different departments at one or more automotive manufacturers.

The concept will be useful for hardware-in-the-loop, software-in-the-loop and real-time validation during test sessions. Using the system from early product development to validation of pre-production systems at the test sessions is possible.

7 ACKNOWLEDGMENTS

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8 LIST OF TERMINOLOGY

DRTSV	"Distributed Real-Time Simulation and Visualization"
MBS	"Multi-Body Simulation Analysis"
PD	"Product Development"
CAE	"Computer Aided Engineering"
DCE	"Distributed Collaborative Engineering"
UDP	"User Datagram Protocol"

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