

Development of an Advanced Driver Model and Simulation Environment for Automotive Racing

Robert J. Rieveley, Bruce Minaker, Marc Maurini, Iva Shallvari and Justin Laport
University of Windsor

Copyright © 2009 SAE International

ABSTRACT

The paper describes a closed-loop vehicle simulation environment developed to support a virtual vehicle design and testing methodology, proposed for the University of Windsor Formula SAE team. Virtual prototyping and testing were achieved through co-simulation of Matlab/Simulink® and Carsim®. The development of the required hybrid-control driver and vehicle models are described. The proposed models were validated with in-vehicle test data. The proposed methods have shown to be effective and robust in predicting driver response, while controlling the vehicle within the developed simulation environment.

INTRODUCTION

In recent years, the Society of Automotive Engineers (SAE) has held a series of competitive student design competitions, that allow undergraduate and graduate student engineers an opportunity to apply theory to real world projects [1]. In particular, the Formula SAE (FSAE) competition has challenged student teams to design and fabricate prototype race vehicles for non-professional weekend autocross consumers with an approximate \$15,000

budget [2]. The student designs and prototype vehicles are judged competitively through a series of static and dynamic evaluations including; design, cost, acceleration, skid-pad and autocross events.

Throughout the past decade, the University of Windsor FSAE (UWFSAE) teams have used an operational structure comprised of a team manager and technical head responsible for the logistic and technical programs of the team. These leaders have typically dealt directly with sub-system design leaders and team members throughout the design and fabrication process. Each design team has been responsible for the design and analysis of their respective vehicle sub-system, as well as, communication of requirements to other design teams that are vital to vehicle operation [2]. Under this system, a design and prototyping methodology has been developed that has been augmented with time and capital saving virtual model-based simulation techniques, similar to those used in academic research and industrial practice [3, 4, 5, 6].

Within the design methodology full vehicle and sub-system models have been designed with Solidworks®, and analyzed using purpose developed and commercial software including MATLAB®, Ansys®, GT Power®, Fluent® and WinGeo®, amongst others [7, 8, 9, 10].

Recently, the UWFSAE team has begun to utilize Carsim® to simulate the dynamic response of proposed vehicle designs [11]. To date, open-loop model-based vehicle dynamics simulations have been executed. However, these simulations have required significant user effort and results have been shown to be dependent on users ability to tune the model. To reduce the dependence on the user, the UWFSAE team desired a driver model to accurately predict the response of a student driver within a closed-loop simulation environment.

In recent years, a large body of academic and commercial work has been focused on the development of driver models for vehicle dynamics simulation. The driver model has been shown to be critical to obtaining robust closed-loop models of driver-vehicle behavior. The definition of these models have typically been grouped into models for longitudinal, lateral and combined control situations. A number of approaches have been found in the literature, generally characterized as classical linear, non-linear, fuzzy, neuro-network and hybrid control methods [12, 13, 14, 15, 16]. Each of these approaches has inherent benefits and limitations when attempting to emulate human response, as outlined in detail by Plochil [17].

The predictive nature of human control has lead to the use of model-based general predictive control (GPC) methods [18]. These methods rely on an internal vehicle model to predict future system states and required control values. Model identification techniques including regression or neural networks have been shown to be reasonably successful in approximating driver behavior from sample data. The work of Bengtsson indicated that the dynamic longitudinal brake and throttle behavior of a driver during highway travel could be estimated using linear regression, subspace-based and GARCH methods [15]. Neural network techniques have been successfully applied to a wide variety of problems and have been shown to predict driver control behavior with great accuracy [16, 19]. In particular, Lin inferred the abilities of radial basis function networks to model human driver control, with the benefits of low training time, as well as, high accuracy and error tolerance [16]. However, the lack of sufficient detailed training data for this study limited the use of fuzzy and neural techniques.

The use of optimal preview control methods for lateral control developed by MacAdam and later by Ungoren attempted to emulate the driver by including a predictive vehicle model element in the determination of the control law [21, 22]. The control is found by minimizing a cost function over a given preview period using the predictive vehicle model. These models have shown to be very effective in producing realistic and robust steering controls. Kiencke developed a significantly more comprehensive hybrid driver model for both lateral and longitudinal control based on a cognitive queuing system, finite state machine and separate GPCs for the lateral and longitudinal dynamics. A parameter was also included in the model to modulate the control response based on the skill

level of the driver [13]. However, limited information regarding this hybrid model was available and an in house model was desired to predict the student driver response.

Vehicle path optimization algorithms have been shown to be an important and effective tool to increase the accuracy of simulated racing laps [24, 26, 27, 34, 35]. Crieis *et. al.* developed a simplified race lap analysis and real-time simulation suite for an FSAE team. However, the algorithms outlined make use of a wide range assumptions and were designed for a simplified real-time simulation of vehicle dynamics using a two degree of freedom yaw-plane model. The work of Brayshaw made use of more advanced quasi-steady state optimization analysis techniques utilizing a seven degree of freedom vehicle model to determine the optimal racing lap times for various vehicle configurations. While this study claimed minimal processing times, the point-by-point optimization technique did not guarantee solution convergence. A more computationally intensive method for race lap optimization was proposed by Casanova that focused on the use of transient optimization using a multi-degree of freedom model. This work can be seen as state of the art, however, the computational time required for a solution was seen as excessive for the level of accuracy required by the desired system. Genetic algorithms have also been used successfully in the search for optimal vehicle configurations and path determination, as indicated by Wloch and Lu respectively [34, 35]. These methods require less problem specific knowledge, but may require more computational time to obtain a solution than some of the other optimal search methods mentioned.

This work details the development of an in house automated closed-loop vehicle dynamics simulation package for the UWFSAE team. The simulations described were achieved through co-simulation of purpose developed MATLAB® models and Carsim®. The development of the required advanced driver model and the encompassing simulation environments are discussed and evaluated. The efficacy of the proposed system to predict driver and overall vehicle response are shown, and a comparison of numerical simulation results and physical test data from the 2007 UWFSAE testing cycle are presented.

SIMULATION ENVIRONMENT

The proposed vehicle dynamics simulation environment required the improvement of the UWFSAE high-fidelity Carsim® vehicle model and the development of a robust driver model and custom data analysis software. The proposed simulation model programmed in Simulink® can be seen in Figure 1.

The required models and tools were designed to include both online and offline processing components. The offline components included track modeling, path optimization and test data processing utilities used to develop and validate models of the proposed vehicle configurations.

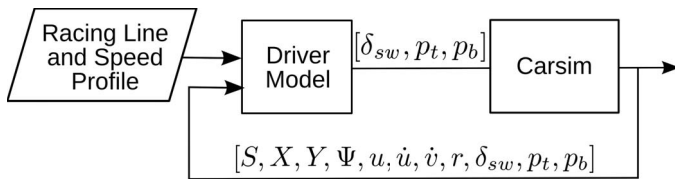


Figure 1: Simulation Model Overview

The required online components included the vehicle and driver models used to run the desired closed-loop simulations. The integration of the proposed software and models within the current design methodology is shown in Figure 2.

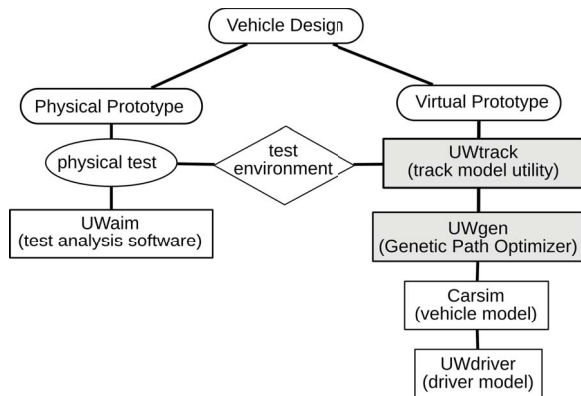


Figure 2: UWFAE Vehicle Dynamics Simulation Environment

VEHICLE MODEL

Within this study, the vehicle model was considered an integral part of the proposed simulation environment. To reduce the development time and increase the reliability of the vehicle model, the use of commercial code was considered. The FSAE vehicle shown in Figure 3 was modeled using a multi-degree of freedom non-linear vehicle model defined within Carsim®. The vehicle model was composed of 21 bodies and had 14 degrees of freedom, and a non-linear tire model [11]. The Carsim dynamics engine was chosen due to specific support for FSAE teams by means of predefined vehicle and subsystem model templates. Within this virtual model, numerical integration of vehicle states is performed using the embedded second order Runge-Kutta (RK2) algorithm. The RK2 method has been shown to work efficiently with tabular models that may not be continuously differentiable, stiff systems and where real-time system state data is necessary [11].

Vehicle sub-systems were modeled using data and models defined during the design and calibration of the 2007 UWFAE vehicle systems. The inertial properties of the vehicle used in this study can be found in Table 1. The engine model for the modified 600cc Honda F4i engine was defined using tabular data from in house dynamometer testing as shown in Figure 4. The included Carsim® clutch, differential and transmission models were utilized



Figure 3: 2007 University of Windsor FSAE Vehicle

with the inclusion of the appropriate ratios. The suspension kinematic effects including; camber, caster, toe and motion ratio versus jounce were provided as tabular data obtained using WinGeo® from Mitchell Software. The Goodyear 20x7.0-13 FSAE tires were modeled using a set of 1996 Pacjeka coefficients, provided by the Formula SAE Tire Test Consortium (FSAE TTC) and the Calspan Tire Research Facility (TIRF) [32].

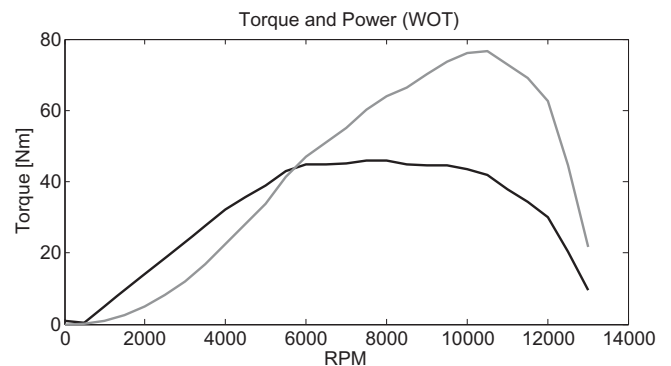


Figure 4: 2007 UWFAE Engine Power and Torque

TRACK MODEL

As outlined by Kiencke [13], the road and path model should provide a detailed reproduction of the road surface and environmental influences, while being connected to the driver model in a meaningful manner. The desired path of the road vehicle should also exhibit continuity of path and curvature and be differentiable, as outlined in [20]. The latter requirement indicating that the path should not have any sharp corners with infinitely large curvature, as this could cause problems with the development a robust path following driver model.

A reconfigurable method of road and path definition was desired during the characterization of this work, that would allow for integration with the purpose developed and commercial software. To achieve this goal, a set of tools were created in MATLAB® that were capable of defining track geometry using an aerial or satellite photo image or acquired GPS data of the track surface. These tools allowed the user to define or update course geometry with obstacles such as pylons or penalty regions quickly and