

## **Abstract: Real-Time and High-Fidelity Simulation Environment for Autonomous Ground Vehicle Dynamics**

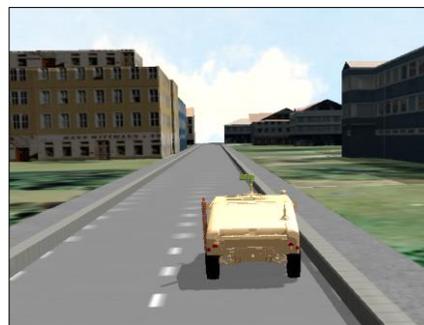
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### **Background and motivation**

With increased onboard autonomy, advanced models are needed to analyze and optimize control design and sensor packages over a range of urban and off-road scenarios. Recent work at TARDEC has attempted to develop a high-fidelity mobility simulation of an autonomous vehicle in an off-road scenario using integrated sensor, controller, and multibody dynamics models [1]. The conclusion was that (a) real-time simulation was not feasible due to the complexity of the intervening formulation, (b) models had to be simplified to speed up the simulation, and (c) interfacing the sensors was exceedingly difficult due to co-simulation. Moreover, the controls developed were very basic and could not be optimized, and only used a rigid terrain model. Integrated simulation capabilities that are high-fidelity, fast, and have scalable architecture are essential to support autonomous vehicle design and performance assessment for the U.S. Army's growing use of unmanned ground vehicles (UGV). In this work, we demonstrate high-fidelity dynamics models for autonomous UGV simulations in near real time using advanced multibody modeling techniques.

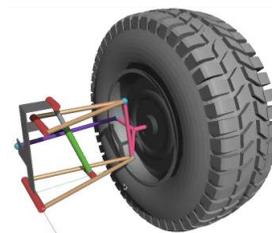


**HMMWV Simulation in an urban environment**

This paper reports on a collaborative project between U.S. Army TARDEC and Jet Propulsion Laboratory (JPL) to develop a unmanned ground vehicle (UGV) simulation model using the ROAMS vehicle modeling framework. Besides modeling the physical suspension of the vehicle, the sensing and navigation of the HMMWV vehicle are simulated. Using models of urban and off-road environments, the HMMWV simulation was tested in several ways, including navigation in an urban environment with obstacle avoidance and the performance of a lane change maneuver.

### **Vehicle hardware modeling**

The HMMWV suspension system is a variant of the common double wishbone suspension. These suspension systems have a large number of distinct bodies that are contained within a single kinematic closed loop. As a result, these suspensions have a large number of internal degrees of freedom. This paper describes three methods for modeling such complex multibody closed chain loops: (FA) fully augmented, (TA) tree augmented, and (CE) constraint embedding. In the FA approach, all the bodies are modeled separately and additional constraint forces are added to enforce the proper motion of the bodies. In the TA approach, the multibody system is treated as a tree topology system with a cut in the closed loop (so it is still topologically a tree) and additional constraints are applied to "close the loop". As a result of recent multibody dynamics research, a third method (CE) is now available, in which the constraints are "embedded" in the formulation to achieve a model with a minimal number of coordinates [2]. In complex closed-chain loops, the CE approach is significantly more efficient than FA and TA approaches and produces exact results without some of the numerical issues exhibited by the FA and CE approaches.



**Suspension model**

### Vehicle sensing, navigation, and control

The HMMWV simulation is based on a vehicle modeling framework called ROAMS developed by the DARTS Lab team at JPL. ROAMS includes a wide variety of vehicle component models to support the inclusion of sensors, navigation, and control. Robotic vehicles in military environments will rely on a variety of sensors, including GPS for position determination and LIDAR scanning to determine the shape of the nearby environment in front of the vehicles. We created models of a GPS sensor and a LIDAR sensor as part of this simulation.

### Environment modeling

To provide suitable simulation environments for the HMMWV model, we created two environments: (1) an urban environment with a range of urban and suburban features, including roads, road curbs, and a variety of buildings (from small to large), and (2) an off-road environment with undulating terrain, some sparse vegetation, and no roads. The environment models include graphical models as well as corresponding, co-registered terrain surface models (digital elevation maps). The graphical representation is important for visualization and for providing the raw data for sensor models (such as visually-based 3D terrain reconstruction). The terrain model is important for the wheel-terrain contact modeling using standard terramechanics approaches (e.g, Bekker).

### Model evaluation and demonstrations

In order to demonstrate the functionality of our HMMWV simulation, we exercised the vehicle simulation in three test scenarios: (1) **Urban obstacle avoidance:** In the first simulation, a goal that was out of sight was selected in the urban environment. The HMMWV simulation then proceeded to navigate along the road to reach the goal using obstacle avoidance to avoid the road curbs. The goal was reached successfully. The HMMWV simulation operated at approximately twice as slow as real time. (2) **Lane change maneuver:** In the second simulation, a maneuver similar to



HMMWV Simulation in off-road environment

a NATO double lane change was performed. The vehicle drove at speed on a straight paved road, shifted over one lane, drove for a short period, and then shifted back to the original lane. This simulation showed expected types of vehicle sway and suspension settling. (3) **Off-road driving:** In the final simulation, the operator used a joy-stick to drive the simulated HMMWV vehicle on undulating terrain. Expected behaviors such as vehicle slipping on steep slopes were observed.

### Conclusions

The HMMWV simulation described in this paper embodies many of the basic features of the real vehicle, including a complex suspension and steering mechanisms, wheel-soil models, navigation, and control. The research described in this paper includes applying advanced multibody techniques such as minimal coordinate representations with constraint embedding to complex unmanned ground vehicles to construct fast mechanical simulations with high fidelity mechanical models. It shows that faster and more efficient vehicle models can be useful to the U.S. Army for future autonomous ground vehicle dynamics modeling and analysis research.

### References

- [1] P. Jayakumar, W. Smith, B. A. Ross, R. Jategoankar, and K. Konarzewski, "Development of High Fidelity Mobility Simulation of an Autonomous Vehicle in an Off-Road Scenario Using Integrated Sensor, Controller, and Multi-Body Dynamics," in 2011 NDIA Ground Vehicle Systems Engineering and Technology Symposium, Dearborn, Michigan, 2011.
- [2] A. Jain, C. Crean, C. Kuo, and M. Quadrelli, "Efficient Constraint Modeling for Closed-Chain Dynamics," in Second Joint International Conference on Multibody System Dynamics, Stuttgart, Germany, May 2012.