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A Constraint Embedding Approach for Complex Vehicle Suspension Dynamics

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Abstract

The goal of this research is to achieve close to real-time dynamics performance for allowing the closed-loop testing of unmanned ground vehicles (UGV) for urban as well as off-road scenarios. The overall vehicle dynamics performance is governed by the multibody dynamics model for the vehicle, the wheel/terrain interaction dynamics and the onboard control system. The topic of this paper is the development of computationally efficient and accurate dynamics model for ground vehicles with complex suspension dynamics.

In this paper, we describe the multibody dynamics modeling approach for our reference 4-wheeled vehicle, which has a double wishbone suspension and associated spring-damper unit at each wheel (Figure 1). Each of these wheel suspensions contains a number of articulated bodies with multiple kinematic closed loops. Despite the large number of internal degrees of freedom, due to the constraints, each suspension has only a single effective degree of freedom.

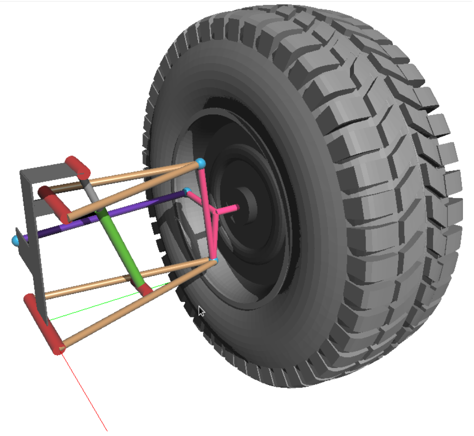

Figure 1: The double wishbone suspension for a single wheel.

The standard approach for modeling closed-chain system dynamics [1] entails decomposing the system into a tree-topology system (or even a collection of independent bodies) and appending the closed-chain bilateral constraints to the equations of motion. A drawback of this approach is the increased computation for solving the equations of motion. Another serious drawback is the error drift that arises during the integration of the multibody dynamics equations of motion. This error drift is usually handled by the use of a differential-algebraic equation (DAE) solver and error correction algorithms to manage the constraint error over time, adding even more computational cost and accuracy error to the dynamics solution. Our real-time performance needs require us to address these major computational drawbacks of the conventional approaches for closed-chain dynamics.

The recently developed *constrained embedding (CE)* method [2, 3] overcomes these key drawbacks for closed-chain dynamics models. In this paper we describe the specific constraint embedding approach we have used for the multibody modeling of the vehicle and suspension dynamics. The constraint embedded technique converts all constraint loops into variable configuration compound bodies which have the same number of degrees of freedom as the number of independent degrees of freedom for the loops they

replace. These compound bodies locally handle their internal degrees of freedom and constraint, effectively hiding them from the dynamics solver. The resulting system topology is once again a tree with only inter-body hinges and no bilateral constraints. The benefit of this approach is that the structure-based O(N) tree algorithms can be directly used to solve the dynamics, and this formulation results in an ODE instead of a DAE. Thus extra error control techniques are not needed. This method however is more complex to implement, since the aggregated bodies now have configuration dependent geometry. While CE method shares the minimal coordinates attribute with projection dynamics techniques [1, 4], its advantage lies in the preservation of the system's tree topology that is necessary for the use of the structure-based tree algorithms.
In this paper we describe the CE modeling approach for the individual wheel suspensions, the overall vehicle dynamics model, and the adaptation of the recursive O(N) dynamics algorithm for efficiently solving the equations of motion. While generic iterative methods can be used to solve the kinematics for the loops, we describe methods to increase the efficiency using analytical techniques. We describe the significant performance speed up and accuracy that we obtain compared with the conventional DAE approaches.

References

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