A Dynamic-Based Approach for Road Vehicle Design : Application to a Three-Wheeler

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Abstract

Context and Objectives

Nowadays, multibody simulations are widely exploited to validate and analyze mechanical systems whose functioning requires high dynamic performances. Thanks to the capabilities of the present computers and clusters, and given the maturity of the recent numerical algorithms, a global optimization of those dynamic systems can be carried out, producing – in a decent simulation time – more satisfactory results than classical approaches like parametric study, experimental plan or sub-systems optimization. In this respect, we focus in this work on the family of road vehicles, characterized by a rather large number of design parameters suited for optimization and we propose a design methodology which takes dynamic issues into account from the earliest stages. In particular, in the proposed approach, the system parameters are classified in order to be processed afterwards by the suitable numerical module of the global design algorithm, rather than the optimizer itself.

The application of the proposed method concerns the optimization the suspensions of a new concept of urban motorized three-wheeler (Fig.1) under development in our laboratory. It consists of a narrow three-wheeled tilting vehicle for which dynamic issues are obvious, given its low track (less than 1 meter) and maximal speed (around 60 km/h).

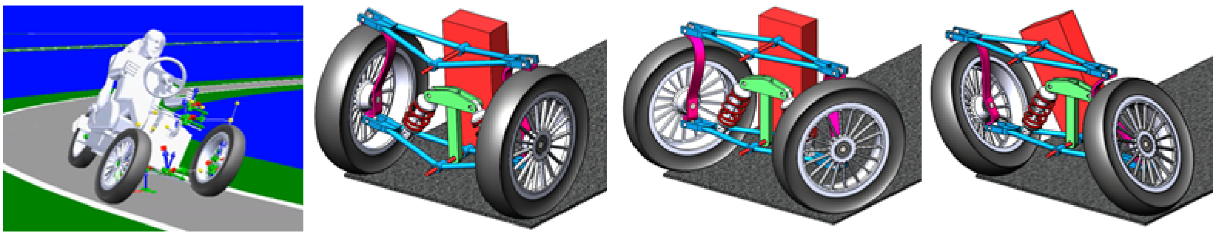

Figure 1: The design of a tilting tricycle requires a dynamic-based engineering approach.

The global design process comprises three successive steps.
Above all, it is assumed that the topology of the vehicle (i.e. type of joints, front and rear suspension linkages , etc) has been fixed by a preliminary mechanical design. This first step also provides realistic initial values for masses, inertia of the main vehicle components.
The second step is the core of the present work. Starting from the above initial design, the parameters are classified according to specific criteria that will define their role in the design process (see next Section). Then, based on well-targeted simulations, the optimization process can actually start to determine the optimal set of parameters, such as component lengths, joints location and orientation, suspension stiffness, controller gain, etc. The objective function is application-dependent and can represent, as usual, a weighted combination of several criteria such as the minimization of the dissipated power in the active suspension of our three-wheeler or the front wheel load transfer in curve.
Finally, On the basis of the above optimized solution, the final mechanical design of the vehicle can start, with possible few iterations on the three steps.

The proposed developments obviously require the availability of a multibody simulator and of an optimization algorithm that the present work does not intend to develop. As regards the multibody model,

the symbolic program ROBOTRAN [1] allows us to produce very efficient C-subroutines for all the kinematic and dynamic sub-models required for the vehicle simulation. The optimization routine comes from the CMA-ES library [2] and is based on a stochastic-type evolutionary algorithm, well-suited to our kind of application.

Methodology and Implementation

The general optimization scheme is depicted in Fig. 2. The objective function to be minimized, F_{OD}, consists of a combination of criteria evaluated based on a time integration of the vehicle direct dynamics. For our three-wheeler, the main criteria are the maximum torque and the mean power of the tilting actuator, the difference between the normal forces acting on the two front tires (as a measure of stability) and an evaluation of the under/over-steering. Additional criteria, i.e. dictated by the vehicle's type of use, might also be introduced here. As regards the parameters, they can come from the geometry (e.g. a rod length) and from specific models (e.g. shock stiffness, controller gains, etc.).
According to Fig. 2, the optimization algorithm iterates on a so-called "trial" composed of a Data conditioner, a Simulator and an Evaluator.

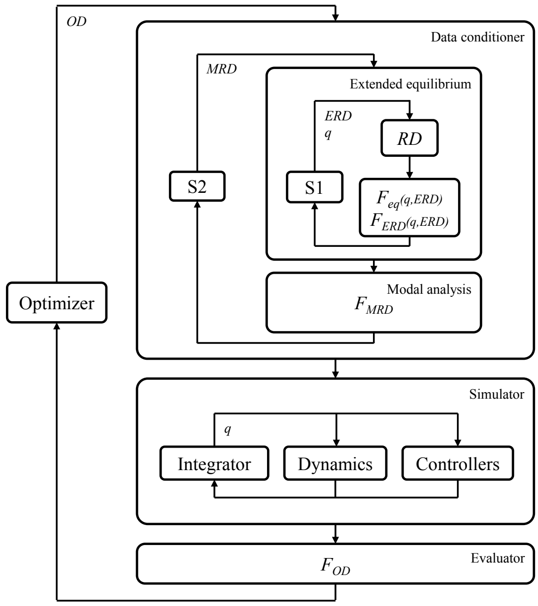

Figure 2: Vehicle optimization scheme

First, the optimizer provides a set of *Optimized Data* (*OD*), corresponding to a subset of the vehicle parameters. That subset is then completed by the Data conditioner which determines the value of other subsets of parameters to take design constraints and dynamic requirements into account. Fed with this full set of parameters, the Simulator block can simulate the three-wheeler motion on a reference trajectory. Finally, the Evaluator computes the objective function F_{OD}, on the basis of the simulation results.
Let us come back to the Data conditioner which is a key step in the proposed process. It consists of two solving loops (Fig. 2). The internal one, called *Extended equilibrium*, simultaneously solves (S1 solver) the equilibrium function, F_{eq}, and the geometrical constraints, F_{ERD}, in terms of the generalized coordinates, q and the so-called *Equilibrium Resulting Data* (*ERD*) (e.g. the neutral length of a suspension spring). *Related Data* (*RD*) refer to parameters obeying symmetry-type rules and are processed upstream of the evaluation of F_{eq} and F_{ERD}. The external loop iterates on the so-called *Modal Resulting Data* (*MRD*) to solve (S2) constraints which aim at satisfying frequency and/or damping requirements (e.g. hop frequency, suspension damping rate). Those "dynamic" constraints are obtained via a modal analysis process F_{MRD}.
The main interest of the approach is that none of the constraints are handled by the optimizer itself, but fully managed inside the trial function, which allows us to decrease the number of optimized data. Moreover, this way, each simulation in the Simulator block is run on a vehicle which satisfies all types of constraints. Thanks to the iterative solvers (S1 and S2), the computation time for the Data conditioner is negligible with respect to the simulation time (Simulator), leading to an efficient optimization process.

As the manufacturing of a first three-wheeler prototype is planned for June 2015, an optimal design based on the present methodology will be available in a few months, and will be presented in more detail in the envisaged conference paper and presentation.

References

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