Kinematic and dynamic optimization of the steering of a tilting tricycle

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Abstract: *The kinematic and dynamic optimization of complex multibody systems opens the possibility of enhancing the design of novel and existing vehicles. In this work, the sensitivty analysis and optimization of general multibody systems is described under kinematics and dynamics conditions and applied to the optimization of the steering of a tilting three wheeler. The approach proposed is general and valid for any multibody system because the starting point for sensitivities are the general kinematics and dynamics equations. The implementation of the sensitivity equations and the numerical experiments were built in the MBSLIM multibody library.*

Introduction

The three-wheeled tilting vehicle shown in Figure 1 is an alternative to common biclycles in which the front wheel and fork are replaced by two front wheels mounted in knuckles, driven by a 1 degree of freedom (DOF) tilting mechanism and a 1 DOF steering system, similar to those employed in four-wheeled vehicles. With these modifications the same driving principle of a classic bicycle keeps for the tricycle, because the front wheels are able to rotate around their axles and the frame is able to roll freely. Nevertheless the desing of the tilting and steering mechanisms of the tricycle is not straigthforward: first, the steering system must approximately satisfy Ackerman's steering condition for any combination of inclination of the frame and rotation of the handlebar; second, aditional kinematic or dynamic conditions can be of interest, for example, achieving a desided relation between the handlebar rotation and the heading of the wheels, or minimizing the coupling between the brakes forces and the steering.

Two optimization problems are solved for the steering: first, the kinematic design optimization; second, the dynamic optimization, equivalent to the kinematic optimization but solved under dynamic conditions using real-drive situations and making it possible to consider dynamic conditions in the objective function or as optimization constraints. All the optimizations performed are gradient-based and they are solved in MBSLIM under the same framework and rely on the multibody general sensitivity equations.

Optimization problem statement

Let us consider a multibody system modeled with $\mathbf{q} \in \mathbb{R}^n$ coordinates. The configuration of the system as a funcion of time, $\mathbf{q}\left(t, \boldsymbol{\rho}\right)$, is given by the solution of the kinematics or dynamics equations and it is considered dependent on a set of parameters $\boldsymbol{\rho} \in \mathbb{R}^p$, which can be geometric parameters in the case of kinematic optimization but also parameters affecting forces or masses in the case of dynamic optimization. Consider an objective function $\psi \in \mathbb{R}$, expressed as an integral over time:

$$\psi = \int_{t_0}^{t_F} g\left(\mathbf{q}, \dot{\mathbf{q}}, \ddot{\mathbf{q}}, \boldsymbol{\lambda}, \boldsymbol{\rho}\right) \mathrm{dt}. \tag{1}$$

The optimization problem consist in calculating the set of parameters which minimize the objective function subject to the optimization constraints $\boldsymbol{\rho}^* = \mathrm{argmin}\left(\psi\right)$.

The sensitivity analysis of the objective function and constraints with respect to the set of parameters can be computed by means of the direct sensitivity or adjoint sensitivity methods and using the kinematic or the dynamic equations presented before [1, 2].

Numerical experiments

The case study for optimal design and optimal control is the tilting three wheeled vehicle shown in Figure 1. The optimal design can be accomplished by means of a kinematic analysis in positions or by means of a dynamic analysis in order to better optimize for the service conditions of the vehicle.

The objective functions considered enforce the satisfaction of Ackerman's steering principle and the relation between the handlebar rotation and the effective steering angle. For the dynamic simulation, the degrees of freedom of the vehicle are predeterminated and the optimization is carried out over this prescribed motion, but for the dynamic simulation, an optimal control function will be added to force the vehicle to fit the desired trajectory and speed, controlling the handlebar and pedals.

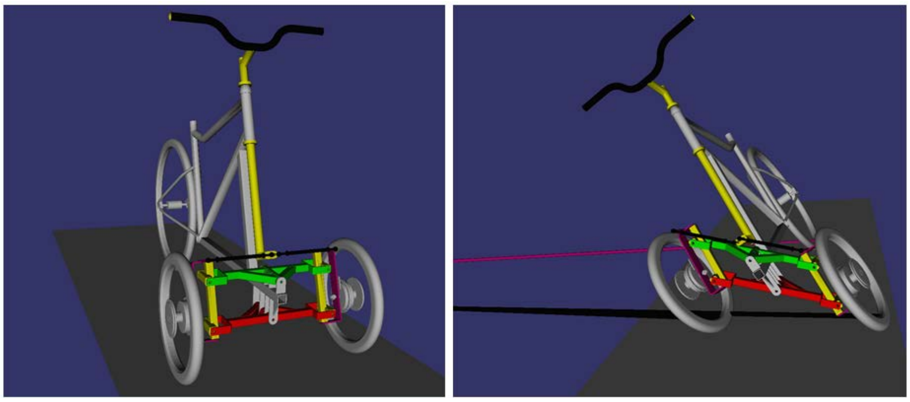

Figure 1: Three wheeled tilting vehicle.

Conclusions

The present work proposes an approach for enhancing the design of mechanical systems using kinematics or dynamics optimizations. The approach proposed is applied to the optimal design of a three-wheeled tilting vehicle.

References

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[2] Dopico, D.; Sandu, A. and Sandu, C.: *Adjoint sensitivity index-3 augmented Lagrangian formulation with projections*, Mechanics Based Design of Structures and Machines, Vol. 50, pp. 48-78, 2022.