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Analytical dynamics based strategy for acceleration control of a car-like vehicle motion

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Abstract

The paper addresses a dynamics modeling method dedicated to control design for constrained mechanical systems. The constraints may be material, control or task based, provided that they are specified by algebraic or differential equations. Theoretical analytical and control developments are related to control acceleration and jerk for car-like vehicles. In vehicle dynamics design and control, jerk and acceleration limits are control objectives related to passenger comfort and vehicle performance. Usually, their profiles are assessed experimentally and then incorporated into vehicle controllers. The paper presents a control strategy, which enables specifying desired profiles of acceleration and jerk by constraint equations.

Keywords: vehicle acceleration and jerk, nonholonomic dynamics, nonlinear control systems

1. Introduction

The paper addresses dynamics modeling dedicated to controller designs for constrained mechanical systems. The constraints on systems may origin from any source, i.e. they can be material, control based or task based, provided that they can be presented in forms of algebraic or differential equations. There are quite a lot of constraints significant from engineering viewpoint put upon system models, which can be presented in equation forms. Interest of this paper is focused upon task based constraints on acceleration and its change, i.e. jerk, imposed on car-like vehicle dynamics. These constraints may be nonholonomic and second and third orders, respectively.

In vehicle design and performance, one of key factors are modeling and eliminating a passenger discomfort, which is strongly related to magnitudes of acceleration and jerk. Comfortable levels of these quantities have different magnitudes in the direction of motion and perpendicular to it; see e.g. Suzuki [1]. Other most common constraints

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put upon a vehicle performance and ride quality properties, as well as in lane changing problems, are upon lateral acceleration and steering velocity as reported in Li and Wang [2] and Papadimitriou and Tomizuka [3]. Jerk and acceleration limits are often considered controller design objectives in car-like vehicles control design or they are additional vehicle performance properties measured. Much of research is focused on an engine torque as a common source to systems controlling vehicle dynamics; see e.g. Dunderski [4] and references there.

In order to improve driving comfort during accelerated vehicle motion, jerk should be eliminated. Nonlinear vehicle acceleration should be converted into a linear, possibly a constant one. Thus, part of the vehicle pulling force, which remains available after overcoming motion resistance, should be constant along the vehicle acceleration path. Controlling the vehicle dynamics by controlling the engine torque may eliminate jerk and improve passenger comfort. In order to control the engine torque during vehicle acceleration, the engine torque curve family for acceleration is required. In Jol and Duboc [5], test beds are designed, from which the engine torque family is obtained for the accelerated vehicle motion. However, accurate results can be obtained only recording vehicle dynamics in real conditions. In Dunderski [4] the engine torque family is obtained by recording acceleration data of an experimental vehicle. There, a choice of acceleration properties gives the acceleration function curve, which intersects the family curves of the engine torques. The way in which the acceleration function curve intersects the engine torque curve family is determined by the selected properties of the acceleration. The model of the acceleration function is stored in a vehicle controller module as an adaptive torque generator. In Bosetti et al. [6] an experimental investigation of human control of vehicles based on the general theories on human movement is presented. The longitudinal and lateral accelerations as well as their relations with theories of motor optimality principles, such as minimum jerk and minimum variance are studied. Data collected during experiments were used to support a driver by an artificial co-driver.

Other approaches to acceleration and jerk estimation, specification of their desired levels and finally controlling them are mostly experimental measurement and approximations based. In Chee et al. [7] three different acceleration profiles: circular trajectory, trapezoidal acceleration trajectory, and fifth order polynomial trajectory, were used. The lateral jerk for a vehicle is specified by selecting the slope of the trapezoid, and the lateral acceleration by choosing the height of the trapezoid. Thus, each acceleration profile is obtained separately by measurements.

Other area of interest in acceleration and jerk is for agile and racing oriented vehicles. They, by definition, should reach specific performance properties. In Jingang et al. [8] dynamics stability and agility of a racing vehicle is investigated and the vehicle lateral jerk and acceleration is taken into account, in a form of an agility metrics, to compare maneuvering performance of a racing car driver and a typical driver.

The paper presents an analytical dynamics modelling method, control strategy architecture based on it, and a subsequent controller design, which, in contrast to many results reported in literature, e.g. see Udwadia and Wanichanon [9], results in final control algorithms that are control theory based, they are the existing ones, already tested and proved their good performance. It means that nonlinear control theory tools are used at the control level. Moreover, the controllers can be the ones dedicated either to holonomic or nonholonomic systems, and both can be applied to nonholonomic ones. A control engineer will know then what sensors are to be used, what is the control convergence and tracking errors when uses the control architecture presented in the paper.

A case study example that illustrates the theoretical analytical and control developments presented in the paper is a problem of control of acceleration and its change for a car-like vehicle. The car-like vehicle has rigid wheels, in contrast to a real vehicle whose wheels have tires and the nonholonomic first order material constraints have to be transformed to the form that represents pneumatic tire characteristics; see Jarzębowska and Vantsevich [10].

The paper contribution is two folded. It introduces latest analytical dynamics methods to handle vehicle performance and driving comfort control problems proposing a new approach for these problems. Also, it proposes a control strategy that can handle practical engineering driving related problems in a unified way.

The paper is organized as follows. In section 2 the task based constraints on vehicle dynamics and driving properties are specified. Also, the analytical dynamics modeling method is reported based on Jarzębowska [11]. Section 3 reports the control strategy architecture as adapted to acceleration and jerk constraints. The example of control acceleration and its change for a car-like vehicle model is presented in section 4. Simulation results illustrate the theoretical development. The paper closes with conclusions, future research prospects and a list of references.