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Optimal workload actuator balancing and dynamic reference generation in active vehicle control

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Abstract

This paper addresses the problem of vehicle attitude control by means of active front steering and rear torque vectoring in the presence of saturating actuators. A novel approach of actuation balancing is proven to be the optimal way to keep the vehicle off saturation or, at least, to postpone the saturation occurrences as much as possible. To this end, a control law is proposed, achieving the tracking goal while keeping the balancing among the actuators. Exponential tracking is shown in nominal (non-saturated) conditions, where the optimality guarantees that the actuators remain as far as possible from their bounds. However, in hard conditions, saturations may still occur and tracking may be lost. Hence, it is shown how to modify dynamically the reference signals in order to compensate the lack of control action of actuators entering a possible saturation condition. As a consequence, less strict references are obtained and the tracking goal is recovered, while keeping the actuators within their saturation bounds. On top of the formal results, the method is validated by means of simulations performed in a non-ideal setting, including parameter uncertainties and unmodeled actuation delays.

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1. Introduction

Active attitude control systems and their integration are among the main research areas in vehicle control. Different active technologies (active braking, active steering, and active differential) were developed and applied in different control schemes (see e.g. [2–7], and references therein). In an integrated control structure, a larger number of degrees of freedom are available for control, thus potentially limiting the saturation occurrences. On top of that, the additional computational effort compared to the use of stand-alone controllers (one per actuator) is rewarded by the increase of performance and by improved comfort and stability conditions.

In [6,7], we addressed vehicle attitude control by using active front steering and rear torque vectoring. The application of an adaptive feedback linearization control [8] was proposed to improve stability in the presence of deviations of the vehicle parameters from the nominal values and rapid variations of road conditions. Most of the aforementioned work did not consider explicitly the issue of actuator saturation, which limits the maximum obtainable performance of mechanical actuators operating under physical constraints.

The problem of input saturation has recently received increasing attention in the control research community and in the automotive field (see e.g. [9,10]). Comprehensive overviews of modern anti-windup approaches are given in [11,12]. In vehicle control, the basic approaches to deal with input saturations aim either at preventing saturations or at managing the occurrence of saturations. A discussion of robust control techniques (including internal model control, H_∞ optimization and anti-windup schemes) applied to vehicular systems can be found in [13]. In [14,15], we proposed some hybrid approaches to the management of the actuator saturations, based on priority schemes, input limiting functions and/or on a modification of the reference signal. Although the tracking performance was satisfactory, this work raised the issue of the closed-loop stability of the resulting hybrid system in the presence of discontinuity of the control actions, which remained in general an open problem.

In this paper, an integrated control scheme of Active Front Steer (AFS) and Rear Torque Vectoring (RTV) is proposed. The main contribution is twofold:

1. A control law, achieving balancing of the workload on the actuators, is designed and exponential tracking is shown in nominal (non-saturated) conditions. Load balancing is a principle that is common to different fields in engineering in order to optimally distribute the workload across multiple resources, balance the utilization, increase reliability, and avoid overload. We pose the balancing problem and solve it as an optimization problem, whose goal is to guarantee that both the actuators remain as far away as possible from saturation conditions.
2. We revisit the idea in [15] of modifying the reference generator, in a different fashion. We show how to modify dynamically the reference signals in order to compensate the lack of control action of actuators entering a possible saturation condition. As a consequence, less strict references are obtained and the tracking goal is recovered, while keeping the actuators within the saturation bounds.

With respect to the preliminary version of this paper [1], the present work considers a 4-dimensional vehicle model, including the two additional actuator dynamics, a formal proof of the main theorem about the workload balancing. It also presents simulations performed in a realistic setting, with parameter uncertainties, noise, unmodeled dynamics and actuation delays.

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