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A switched and scheduled design for model recovery anti-windup of linear plants

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Abstract

We provide two nonlinear solutions to the model recovery anti-windup (MRAW) design problem, both of them relying on the definition of a set of nested ellipsoids in the state space of the anti-windup dynamics. Each ellipsoidal set arises from a convenient trade-off between size of the ellipsoid and guaranteed exponential convergence rate induced by the corresponding saturated feedback. The first solution is given by a hybrid selection of the MRAW stabilizer, relying on a natural hysteresis switching mechanism. The second solution corresponds to a Lipschitz but non-differentiable scheduled selection, which essentially smoothens out the discontinuous nature of the nested ellipsoids. We discuss the role of our design architecture and establish a number of important properties induced by the proposed controllers. Their effectiveness is comparatively illustrated on a few example studies.

Keywords: model recovery anti-windup, scheduled stabilizer, switched stabilizer, bounded control

1. Introduction

Actuator saturation is one of the most frequent hard nonlinearities encountered in control system implementation. When applying any type of control design to a real plant, the control engineer needs to account for the effects of the maximum and minimum control effort allowable for the actuator available on the experimental system. It was observed already from the 1940s that the presence of saturation often caused undesirable behavior and that suitable fixes were necessary to address the arising problem (this fact was actually one of the main motivations for the absolute stability results of the 1950s and the sector properties of static nonlinearities).

A popular approach to deal with saturation, which dates back to the 1960s (see, e.g., [9]), is the so-called anti-windup approach, wherein an “unconstrained controller” is assumed to perform desirably in the absence of saturation (equivalently, when signals are small enough on the saturated closed-loop) and “anti-windup” corrections are necessary for larger signals that would interest the flat region of the saturation, thereby causing performance loss and often instability. The ultimate goals of anti-windup designs are that: 1) the unconstrained behavior imposed by the “unconstrained controller” on the plant is fully reproduced whenever saturation is not activated (namely for small enough signals); 2) for larger signals the performance is close (as close as possible) to the unconstrained one, and stability is retained as much as possible given the hard limits imposed by the presence of saturation. Initially, anti-windup control was mainly an application driven discipline and most of the results available in the literature were not applicable to general classes of control systems, rather being specific naive solutions for some experimental problems. Toward the end of the 1980s, this lack of formality in the field has been pointed out (see, [8]) and the need of general solutions to the anti-windup augmentation problem led to in an increase of the research effort in the following years. Comprehensive surveys of the first anti-windup solutions are given in [21, 2, 28]. Starting from the mid 1990s, several high performance solutions to the anti-windup problem started to appear. Many of these rely on the so-called reference governor or command governor scheme which is most directly applicable to discrete-time control systems (see, e.g., [16, 1] and references therein). Other ones are mostly related to continuous-time cases and rely on the use of linear matrix inequalities (LMIs) together with absolute stability and generalized absolute stability concepts (see, e.g., [31, 18, 25] and references therein). Some very detailed presentations of the above historical overview of anti-windup can be found in the surveys [14, 36] and in the two books [57, 35].

Among the many aspects that make the anti-windup design challenging is that it inherits well-known intrinsic limitations already known for bounded stabilization. In particular, it was already proved in [34] that global bounded asymptotic stabilization of a linear plant can only be obtained if the plant has eigenvalues in the closed left half plane. Global exponential stabilization via bounded input can then only be obtained if

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