



Sliding manifold design for linear systems with unmatched disturbances

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Abstract

This paper offers an efficient sliding manifold design method that minimizes the impact of unmatched disturbances onto SM dynamics and system accuracy. System sensitivity upon unmatched constant or slowly varying external disturbance vector is evaluated by the steady-state dependent criterion function. An infinite set of sliding manifolds that minimize the chosen optimization criterion is determined and a way of selecting a manifold out of that set that provides adopted SM dynamics is suggested. The proposed approach has been demonstrated on numerical examples and verified by simulations.

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1. Introduction

The main reason for the unabated interest in variable structure control (VSC) systems that lasts more than half a century is their theoretical invariance to parameter perturbations and exogenous disturbances in ideal sliding mode (SM). Conditions for such prestigious property were revealed and formulated in [1] by Draženović (1969), originally termed as invariance conditions, nowadays worldwide known as the matching conditions. While SM dynamics is insensitive to the matched disturbances, it is affected by the unmatched ones. In some cases SM along certain

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manifolds can result in severe dynamics deterioration under action of unmatched disturbances. This is the reason why SM control (SMC) systems with unmatched disturbances have attracted certain attention of the scientific community.

Several approaches to deal with unmatched disturbances within the context of SMC can be recognized. They make in general the two groups according to the nature of the disturbances.

The first group considers unmatched uncertainties of parametric nature, i.e. disturbances that occur due to parameter perturbations. A nonlinear control strategy providing motion both close to the sliding manifold and as close as possible to the ideal SM dynamics was proposed in [2] for a practical uncertainty class.

Dynamical approach to sliding manifold formulation is another aspect that can explicitly deal with unmatched uncertainties in SM. In [3] certain states were treated as inputs to the reduced order system that describes SM dynamics. Using an adaptive technique to design fictitious controllers for these inputs, the unmatched uncertainties can be tackled. This technique assumes certain constraints to the unmatched uncertainties as well as on-line estimation of the uncertainties present in the reduced-order system. A similar concept of pseudo-control inputs into sliding function was utilized in [4,5]. A new invariance condition in terms of LMI providing a linear sliding manifold that ensures SM dynamics to be stable and invariant to the matched and unmatched uncertainties was proposed in [6]. However, it is important to emphasize that the considered type of unmatched disturbances diminish as system states approach origin, so the asymptotic stability can be achieved.

When it comes to the other type of unmatched disturbances, which besides parametric contain external disturbances as well, asymptotic stability is never attained. A non-vanishing unmatched disturbance will force system trajectory not to converge into the origin but to wander in its neighborhood along the sliding manifold. The only way of handling this problem is to construct a sliding manifold that in some sense minimize SM dynamics sensitivity upon the unmatched disturbances. A natural approach to this problem is to choose the sliding manifold that does not amplify the unmatched disturbance that affects SM dynamics, which was proposed in [7] in integral SMC of nonlinear systems. Another appropriate sliding manifold selection is given in [8] that guarantees convergence of linear system trajectory into the minimal invariant ellipsoid. Both methods consider disturbances of general type. However, it has been noticed in [9] that in case of constant unmatched external disturbances in linear systems there is a sliding hyperplane construction that provides better system accuracy than the one recommended in [7]. System accuracy has been evaluated through the steady-state vector norm.

Although it seems simple, consideration of constant disturbances deserves attention due to indication in [9] that there is no universal sliding hyperplane design that is equally effective for various types of disturbances and criteria. In addition, constant and slowly varying disturbances are frequent and important enough to deserve separate treatment.

Therefore, this paper further pursues minimization of a steady-state based criterion function for linear multivariable systems subjected to unmatched constant or slowly varying external disturbance vector. A new sliding manifold design method is developed that very efficiently finds an infinite set of sliding manifolds that minimize the optimization criterion. Frequency range of reliable applicability of this method is suggested. The method relies on the projector theory, which was employed in VSC systems in [10]. Furthermore, the possibility of an arbitrary choice of SM dynamics under the minimization requirement is examined. Eigenvalue constraints are revealed in certain cases, for which a way to select and attain the feasible SM dynamics is suggested. The proposed sliding manifold design approach has been demonstrated on numerical examples and verified by computer simulations.

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