PREDICTIVE GENERALIZED MINIMUM VARIANCE CONTROL OF NONLINEAR MULTIVARIABLE SYSTEMS WITH NON-ANALYTICAL MODULES

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Abstract—For most of the control methods, it is implicitly assumed that a mathematically analytical model can be obtained before control design. This is not always feasible for many engineering systems whose analytical models are either very difficult or expensive to obtain. To handle this situation, linearization or identification techniques are usually deployed to obtain an analytical model. This paper, however, proposes a novel method to tackle directly those systems with non-analytical modules. The method does not rely on the inversion of the nonlinear system and is henceforth computationally economic. Important results are obtained on control design for nonlinear multivariable systems with non-analytical modules. Input saturation, robustness and practical implementation issues are also discussed. The proposed method is finally validated through its application to a robotic manipulator.

Keywords—Nonlinear systems, nonanalytical modules, nonlinear predictive control, input saturation.

I. INTRODUCTION
Nonlinear systems theory has developed rapidly over recent decades including concepts such as zero dynamics and normal forms (Isidori, 1995), passivity and dissipativity (van der Schaft, 1996), nonequilibrium theory (Byrnes, 2000), etc. As a consequence, a number of nonlinear control design techniques have been well established such as feedback linearization (Isidori, 1995), recursive designs including backstepping and forwarding (Sepulchre et al., 1997), energy-based control design for nonholonomic dynamical systems (Block et al., 2003) and nonlinear model predictive control (Mayne et al., 2000), to name just a few.

For most of control design methodologies, however, it is implicitly assumed that a mathematically analytical model can be found as expressed by differential/difference equations, or differential-algebraic equations. In many engineering systems, however, analytical expression of the system models can be very difficult or expensive to obtain. In fact, many practical systems are expressed using lookup tables or even C/Fortran codes. To handle this situation, linearization or identification techniques are used to first obtain a mathematically analytical model of the system under consideration, before any particular control design method is deployed. In this paper, however, a new approach is proposed that control design can be carried out directly based on the nonanalytical models. Essentially a design framework for nonlinear multivariable systems with non-analytical modules is introduced where many specific control methods can be exercised. In this paper, a predictive control method is presented to illustrate the design framework. A brief introduction to predictive control is given in sequence.

Model Based Predictive Control (MBPC) has been very successful in industrial applications over the past three decades. The most popular predictive control algorithms are Dynamic Matrix Control (DMC) (Cutler and Ramaker, 1979; 1980) and Generalized Predictive Control (GPC) (Clarke et al., 1987a; 1987b), although almost all vendors have adopted a DMC-like approach (Qin and Badgwell, 1996; Morari and Lee, 1999). However these approaches are based on linear models and are thus inadequate to handle systems described by nonlinear models. Moreover, most systems are inherently nonlinear and this necessitates developing methods utilizing nonlinear models to achieve optimal performance over wide range of system operations.

There has been a rich history of research in the field of nonlinear model predictive control (NMPC). Many approaches have been proposed such as infinite horizon NMPC (Meadows and Rawlings, 1993) and quasi-infinite horizon NMPC (Chen and Allgöwer, 1998), contractive NMPC (De Oliveira and Morari, 2000), etc. Excellent reviews of existing NMPC techniques can be found in Mayne et al. (2000), De Nicolao et al. (2000), Rawlings (2000). Commercially available NMPC technology can be found in Qin and Badgwell (2003). Some new developments and challenges in NMPC can be referred to Magni et al. (2009) and Grüne and Pannek (2011).

One of the key questions in NMPC is closed-loop stability. As a result, most of the approaches employ a Lyapunov-based strategy where construction of Lyapunov functions for stability guarantee, e.g. via the introduction of end constraints becomes the main concern. Unlike these “stability guaranteed” approaches, the control strategy introduced here is motivated by the need to produce a control law, which is very simple to implement in industry (Grimble, 2008). In fact, many of the stability-guaranteed NMPC requiring on-line optimization are computationally expensive (De Oliveira and Morari, 2000) and there is a natural demand for a practical control law for nonlinear systems that has a sound but relatively simple theoretical basis. A promis-