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Velocity Observer Based Controller Design for Second Order Systems, with Application to Constrained Robotic Systems

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Abstract— **In this note two related problems for stabilization of a class of Lipschitz nonlinear systems are considered. (1) observer design for the estimation of system states (2) observer based controller design which consists of two parts: observer part that estimates system states from the measured ones and a linear feedback part that utilizes these estimated states. A Lyapunov-based stability analysis is developed to show that this computationally efficient controller results in global asymptotic stability of the estimation and tracking error. An interesting feature of the developed method is that it can be used for a wide class of mechanical systems including serial and parallel robotic systems with kinematic constraints. Numerical validations of the proposed method on a slider crank as a sample of constrained robotic systems is presented.**

I. INTRODUCTION

VARIOUS methods for designing nonlinear controllers have been reported in the literature [1]. In spite of these efforts, today most of the robotic systems, as a wide class of nonlinear systems, are still controlled by some kind of prevalent linear state feedback controller [2], [3].

Recently due to the increasing demands on productivity and efficiency of robots, there has been a tendency toward developing fast lightweight robotic systems which are actuated by direct drive motors. The dominant disadvantage of such newly developed systems is characterized as high nonlinear and coupled dynamics. Nevertheless, as shown in [4]-[7], even for such systems the classical PD controller works efficiently.

One characteristic feature of the state feedback controller is that it requires both position and velocity measurements, albeit much of this requirement is not achieved.

Particularly link velocity often targeted for elimination because of the noisy nature of tachometer based velocity measurements. High precision velocity sensors are frequently leaved out due to the savings in cost, volume, and weight [8].

Hence the efforts of control designers shifting towards the reduction of the number of external sensors required to generate the torque input control signal.

Practically these difficulties have been partly solved by the substitution of measured velocity by some kind of time derivate approximation which was computed from clean position measurements and can be simply got from digital encoders. For middle range velocities, this idea works well.

This method suffers from a serious limitation, since on the one hand it provides poor velocity approximations and on the other hand it is not appropriate for high velocity measurements which require small sampling time. Thus a number of robotic control methods have been recently proposed which eradicate the velocity measurement problem by utilizing a velocity observer in the control loop.

It is notorious that an observer design problem itself is a challenging one which has various applications such as output feedback control, system monitoring, process identification and fault detection.

The solution of observer problem for linear time invariant systems is the use of the well known Luenberger observer structure in which a constant matrix is used to stabilize the observer error dynamics to achieve asymptotic convergence. For nonlinear systems several methods are proposed.

In [9], a nonlinear system is transformed into a linear one and then an observer is designed for the linearized system. Nevertheless, the conditions to attain completely linearizable error dynamics are lenient, and finding the required nonlinear state transformation is necessary.

In [10] an observer for nonlinear systems with Lipschitz nonlinearities is developed through the solution of a Lyapunov equation or a Riccati equation [11]. Unfortunately, this approach suffers from a serious limitation which caused the Lipschitz constant of the nonlinearity to be small.

The idea of designing high gain observers was proposed by Khalil and Esfandiary [12]. In [13], slotine and canadus de wit design a sliding observer with the compensation of system parametric uncertainty.

Berghuis et. al [14], used a passivity approach to develop an observer based controller for robot motion control utilizing only position measurements.

Recently, Khelif et. al [15], have designed a variable structure controller to control robots needless of velocity measurements.

In [16], Herenida proposed a high gain observer based controller for robot manipulators. Roughly speaking, the approaches given in [17], [18] yield the same type of stability result using absolutely different control structures.

Output feedback control of nonlinear systems in triangular form with nonlinearities satisfying certain growth conditions was considered in [19], [20]. Also a backstepping design procedure for dynamic feedback stabilization for a class of Lipschitz nonlinear systems with unknown time varying parameters are considered in [21]. In [22] a solution to the output feedback control problem for Lipschitz nonlinear

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