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Unknown input sliding mode functional observers with application to sensorless control of permanent magnet synchronous machines

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Abstract

This paper illustrates a method of designing a sliding mode linear functional observer for a system with unknown inputs. The existence conditions for the observer are presented. A structure and design algorithm for the sliding mode observer is proposed. The proposed algorithm is then applied for sensorless control of Permanent Magnet Synchronous Machines.

1. Introduction

Sliding mode observers differ from more traditional observers, e.g. Luenberger observers, in that there is a non-linear term injected into the observer depending on the output estimation error. The concept of sliding mode was originally applied to control system design [1,2] and later applied for estimating system states [2–6]. State estimators that utilize the concept of sliding mode are referred to as Utkin observers in the literature [3]. Sliding

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mode functional observers estimate linear functions of the state vector of a system without necessarily estimating all the individual states while ensuring that sliding will occur on a manifold where some function of the output prediction error is zero. Since only required functions are estimated with functional observers, these observers have lower order than full order observers, the order of the functional observer can be as low as the number of functions estimated. Much of the work here has been motivated by the work of [7,8], where the importance of sliding modes is demonstrated in *Variable Structure Systems*. The practical applications of sliding mode observers in power and control have been illustrated in [9–12] most importantly in the field of induction motor control. It is also noted in [13] and also in other articles on sliding mode observers [14,15] the robustness properties of these type of observers. Motivated by reported robustness properties of sliding mode observers, in this paper we present the concept of sliding mode functional observers and apply it for sensorless control of Permanent Magnet Synchronous Motors (PMSM).

One of the most intriguing aspects of sliding modes as described in [3] is to switch between two distinctively different system structures (or components) such that a new type of system motion, sliding mode, exists in a manifold. This certain peculiar system characteristic which is a consequence of the switching function is claimed to result in superb system performance which includes insensitivity to parameter variations, and complete rejection of disturbances [3]. These properties of sliding mode are investigated in this paper by simulating the proposed observer in sensorless control of PMSMs.

In the literature the state estimation problem for unknown input systems is well researched [16–20]; however, application of sliding mode concepts to estimate a linear function of the state vector has not yet been addressed. In this paper, we present conditions for designing sliding mode functional observers when the system is subjected to unknown inputs. Under special circumstances, the existence conditions derived in this paper reduce to the existence conditions for the Utkin Observer and also reduce to the well known matching and observability conditions required for the design of an unknown input state observer.

This paper is organized as follows: Section 2 provides a general outline of the problem to be solved. This section will provide a description to the unknown input system of equations and the corresponding sliding mode linear functional observer structure that will be applied. Section 3 describes the conditions for the existence of the sliding mode functional observer and based on these conditions a design algorithm is presented. Section 4 provides the application of the theory to speed sensorless control of PMSMs. Finally, Section 5 presents the conclusions of the paper.

2. Problem statement

Consider a linear time-invariant system described by

$$\dot{x}(t) = Ax(t) + Bu(t) + Dv(t) \tag{1}$$

$$y(t) = Cx(t) \tag{2}$$

$$z(t) = Lx(t) \tag{3}$$

where $x(t) \in \mathbb{R}^n$, $u(t) \in \mathbb{R}^m$, $v(t) \in \mathbb{R}^q$ and $y(t) \in \mathbb{R}^p$ are the state, known input, unknown input and the output vectors, respectively. $z(t) \in \mathbb{R}^r$ is the vector to be estimated. The pair (C,A) is detectable, (A,B) is controllable, $A \in \mathbb{R}^{n\times n}$, $B \in \mathbb{R}^{n\times m}$, $C \in \mathbb{R}^{p\times n}$, $D \in \mathbb{R}^{n\times q}$ and $L \in \mathbb{R}^{r\times n}$ are known constant matrices. It is noted here that D represents the unknown input matrix. Without loss of generality, it is assumed that $Rank(C) = p$, $Rank(L) = r$,