Adaptive Neural Actuator Fault Tolerant Control for Discrete-time Unknown Nonlinear Systems

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1. EXTENDED ABSTRACT

Control systems constitute a fundamental stage in the development and implementation of new technologies and its advancements. As technology has advanced, so has systems' complexity, in such a way that modern control systems must be capable of ensuring increasingly complex control objectives. Today, the systems to be controlled must not only consider their non-linearities, uncertainties and disturbances, which are phenomena already well studied; now it is also necessary to ensure their behavior under the presence of more challenging conditions such as those presented by faults, see M. T. Hamayun and Alwi (2016).

Fault-tolerant control schemes are an important aspect in safety critical systems and seek to maintain overall system stability and acceptable performance in the face of faults and failures within the system as in M. T. Hamayun and Alwi (2016). There are different kind of classification about faults, in M. T. Hamayun and Alwi (2016) it is defined that faults can be classified as actuator fault, sensor fault or component fault, their location. In this talk, different fault profiles, associated with the actuators, are considered, faults at the component and sensor faults are not considered. Types of actuator can be classified as float failure, lock in place failure, hard over failure and loss of effectiveness; evidently there are faults that are easy to deal with them and there are hard fault that can be very destructive and they can cause irreversible damage to the system as in H. Alwi and Tan (2011). Therefore, increasing demands for safety, reliability and high system performance have motivated the need for fault-tolerant control and has stimulated research in this area. For the design of fault-tolerant controllers, many different design paradigms have been proposed in M. T. Hamayun and Alwi (2016).

On the other hand, modern control systems require the availability of a mathematical model to be controlled or at least a nominal one, in this kind of requirement retards and complicates the controller design, an approach that has been gaining significance is the design of model-free controllers most of them designed based on artificial-intelligence approaches. In this route, artificial neural networks have been shown to be a suitable tool to produce an accurate mathematical model, such model can be used to predict, to analyze, to simulate, to emulate or even to design control systems. Furthermore, from the great amount of successfully application it is clear the effectiveness of sliding mode controllers due to their robustness as well as the effectiveness of intelligent methodologies to develop model-free controllers as the presented at: I. Salgado and Chairez (2019); X. Yin (2020); H. Zhang and Y.Wang (2020b); H. Liang and Huang (2020); H. Zhang and Y.Wang (2020a); P. Du and Lam (2020); R. Yang (2020); V.-T. Nguyen and Tran (2019), mainly the use of artificial neural networks. Then it would be evident the combination of neural networks and sliding mode control to develop a fault-tolerant controller that can handle real-world applications. The combination of the advantages of neural networks and sliding mode control has resulted in a robust control technique named neural sliding mode control for instance see: I. Salgado and Chairez (2019); X. Yin (2020); H. Liang and Huang (2020); R. Yang (2020); V.-T. Nguyen and Tran (2019).

In this talk, we apply the proposed scheme to control a three-phase induction motor. It is important to note that the proposed scheme is developed assuming that the plant model, as well as plant parameters and external disturbances (load torque) are unknown. Furthermore, the proposed methodology can deal with well known uncertainties as rotor parameter variations with frequency due to skin effect, and other nonlinear imperfections such as heating, main flux path saturation, leakage variation or flux migration due to rotor skew and external disturbances variations, such as load torque changes, without any previously knowledge of their dynamics. Most of these phenomena are presented during induction motor operations, see F. Khorrami and Melkote (2003).

Additionally, induction motors are one of the most preferred actuators for industrial applications due to their reliability, ruggedness and relatively low maintenance cost, see: E. Quintero-Manriquez and Felix (2016); F. Khorrami and Melkote (2003). However, the occurrence of chaos, parameter uncertainties, presence of external disturbances and asymmetrical input-output constraints, usually degrades stability and precision of induction motors. This can commonly be found in electric vehicles, electric elevators, compressors, robotics, machine tools, aerospace, among other mechatronic systems. Hence it is meaningful

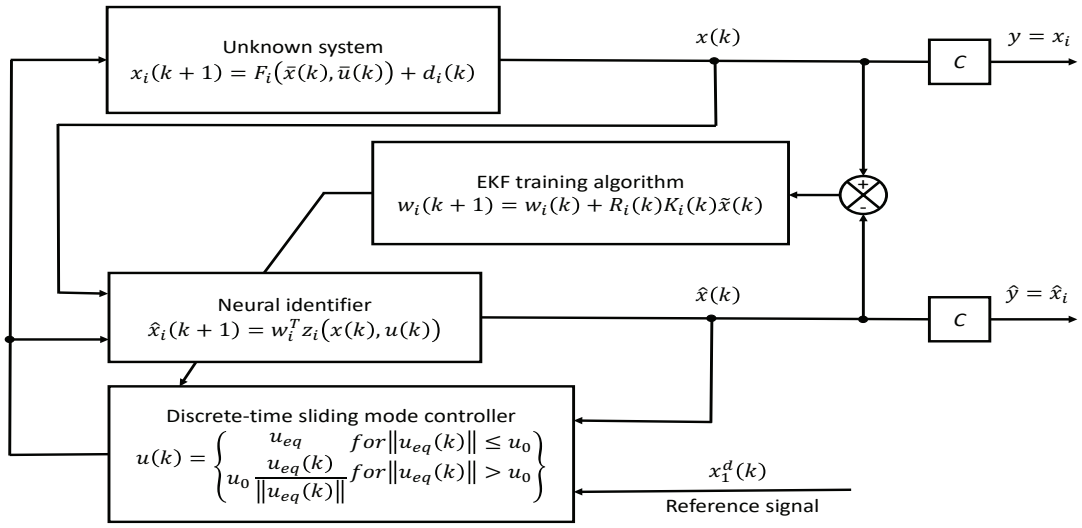


Fig. 1. Actuator fault-tolerant control scheme using an adaptive neural sliding mode strategy.

to develop a controller with strong resilience, reliability, robustness and high precision that can deal and compensate all previously described problems.

This talk focuses on controlling the rotor flux magnitude and electromechanical torque for trajectory tracking of time-varying reference signals, this kind of control is important for different type of applications, especially for mechatronic and transportation systems. For instance, torque control scheme is one of the most important role in the performance of an electric vehicle, acceleration pedal is used as a torque reference for the electric motor control and it is defined in real-time according to navigation conditions, therefore it is important that the controller can handle with these types of reference profiles, which is not always considered for traditional electromechanical torque controller in induction motors, see: E. Quintero-Manriquez and Felix (2016); Pimkumwong and Wang (2018); J. Rodriguez and Miranda (2018); Basri and Mekhilef (2016).

This talk proposes an actuator fault-tolerant controller for a three phase induction motor. Mathematical models are a central tool to design modern control techniques, however, an accurate model for complex systems it is not always available, therefore in this paper a recurrent high order neural network, trained with an extended Kalman filter, is proposed to produce a mathematical model for a three phase induction motor. The neural model is combined with a discrete-time sliding mode controller with a modification that allows the control system to compensate the presence of actuator faults. Simulation results are included in order to show the applicability of the proposed scheme under different actuator fault profiles.

The whole fault-tolerant control scheme is depicted in Fig. 1, from this scheme for the closed-loop system, it is easy to see that the neural network models the entire system, including: actuator faults, state uncertainties, input uncertainties, unmodelled dynamics, external disturbances, sensor errors, noises, actuator limitations, among others.

Fig. 2, shows simulation results for actuator faults applied to an induction motor, the plant operates on open loop until $t = 1.5s$ then, the sliding mode neural controller is applied to achieve trajectory tracking for electromechanical torque as well as for flux magnitude, for $2 \le t \le 2.2$ a first fault is inserted, then a second fault is inserted for $3 \le t \le 3.2$, besides the induction motor is working under external uncertainties applied as a load torque that varies from its nominal value of $1.0Nm$ to a value of $1.2Nm$, this load torque is considered unknown for the neural control design, besides the controller is designed under the assumption of the model unknown for the induction motor, then this application shows the capability of the proposed scheme is a fault tolerant controller that can deals with unknown uncertainties, unknown external disturbances and unknown dynamics without the need of a previous knowledge of plant model. This application has relevance for industrial applications due to induction motors is one of the most used actuators for industrial processes.

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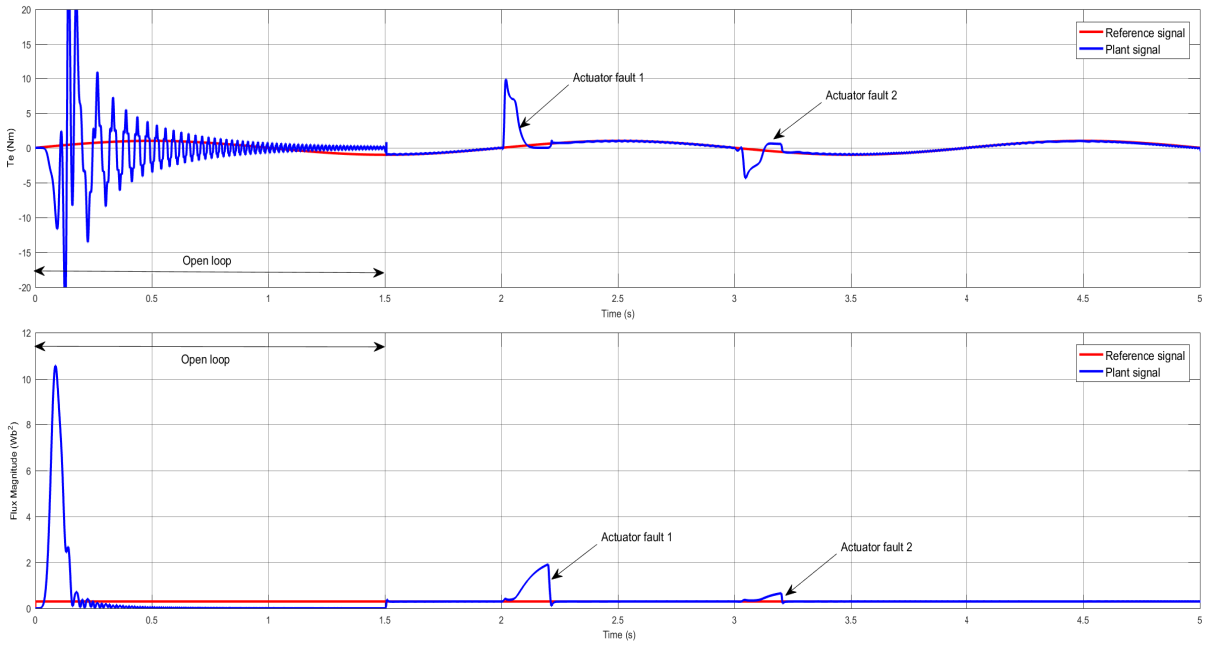


Fig. 2. Simulation results for trajectory tracking.

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