Preface

The state of a process specifies its behavior, and many control schemes such as inverse dynamics and feedback linearization rely on the availability of all the system states. However, in many practical systems only the input and output of a system are measurable. Therefore, estimating the states of a system plays a crucial role in monitoring the process, detecting and diagnosing of faults, and achieving better performance. Furthermore, most practical systems are nonlinear, and using linearization or quasi-linearization methods limits the estimation accuracy to a small dynamic range. Several conventional nonlinear observers have been proposed during the past couple of decades. However, most of this work relies on exact a priori knowledge of the system nonlinearities. This assumption is rarely satisfied for most practical processes where determining an exact model is quite a difficult, if not impossible, task. Robot manipulators with flexible joints or links are good examples of such systems. Flexibility in a manipulator causes extreme difficulty in modeling manipulator dynamics and becomes a potential source of uncertainty that can degrade the performance of the manipulator and in some cases can even destabilize the system. Thus, model-based observers are not best suited for such systems.

Capabilities of neural networks for identification, observation and control of nonlinear systems have been investigated in both off-line and online environments. In fact, the adaptive behavior of neural networks makes them powerful tools for state observation without any *a priori* knowledge about the system dynamics. Several neural network-based observers have been proposed in the literature for state estimation of nonlinear systems. However, most of these techniques suffer from restrictive assumptions such as (a) a strictly positive real (SPR) condition on the output error equation, (b) scalar-valued nonlinear functions, (c) Linear-in-Parameter Neural Networks (LPNN), (d) a special class of nonlinear systems (e.g. affine nonlinear systems), (e) lack of proof of stability, and (f) a complex weight-updating mechanism, which prevent the use of such observers to real-world applications.

On the other hand, in many control applications unpredictable behavior such as poor performance or even unsafe operation can result from small abnormal deviations (malfunctions) either in the sensors and actuators, or in the components of the process. Hence, an exceptional level of autonomy is required. Recognizing that fault detection and identification is an essential capability of an autonomous system, there is a high demand for development of novel methods for fault detection, isolation, and recovery systems.

The objective of this monograph is to address the problem of state estimation, system identification and observer-based fault detection and isolation (FDI) for nonlinear systems. Towards this end, a neural network-based adaptive observer for a general model of MIMO nonlinear systems is first proposed with no a priori knowledge about the system nonlinearities. The neural network is nonlinear in its parameters and can be applied to many systems with arbitrary degrees of nonlinearity and complexity. The online weight-updating mechanism is a modified version of the backpropagation algorithm with a simple structure together with an e-modification term that is added for enhanced robustness to unmodelled dynamics and uncertainties. The SPR assumption imposed on the output error equation is also relaxed. The proposed structure is then employed for the system identification problem. The proposed state estimation scheme is employed to develop a new observer-based fault detection and isolation scheme. Several types of faults, namely actuator bias faults, actuator gain faults, and sensor bias faults are considered. The proposed method relies on only output measurements and is also robust to dynamic uncertainties as well as disturbances and measurement noise. Moreover, the fault detection, isolation, and estimation steps are all unified, i.e., neither extra measured/calculated signals nor a separate fault isolation policy is required to isolate the faults. For each developed algorithm, mathematical proofs of stability are given by using Lyapunov's direct method. The effectiveness of our proposed state estimation/identification/fault detection approaches is demonstrated through extensive simulations as well as experimentations that are carried out on highly nonlinear systems. The case studies include flexible-joint and flexible-link manipulators, satellite attitude control systems with reaction wheel and magnetorquer type of actuators (simulations), and a 3 DOF macro-micro manipulator and a 6 DOF industrial manipulator, namely the PUMA 560 (experiments).

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H.A. Talebi F. Abdollahi R.V. Patel K. Khorasani