

402e Nonlinear Diagonal Unknown Input Observers for Fault Diagnosis

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Process fault diagnosis is the problem of identifying the causal origins of faults in a process, given current sensor data and a priori knowledge about the process behaviour under normal and abnormal conditions. Fault diagnosis is increasingly becoming important for process safety, improved product quality and process economics. Fault diagnosis strategies may be broadly classified as qualitative model-based, quantitative model-based and data-based approaches.

While, there have been a number of papers that have discussed the data-based and qualitative model-based approaches, very little has been published on the use of quantitative model-based approaches for fault diagnosis in chemical engineering systems. Relying on analytical redundancy, these methods for fault diagnosis check the actual system behavior against a parallel system model for consistency. Any inconsistencies, also called residuals are artificial signals reflecting the potential faults in the system and can be used for detection and isolation purposes. The residuals should be close to zero when no fault occurs but show significant values when the underlying system changes. Apart from being sensitive to the faults, the residuals may be chosen so that they are immune to the effect of unmeasured disturbances (unknown inputs) or equivalently, the residuals are said to be decoupled from the unknown inputs. One model based method of residual generation that uses a dynamic system model and a feedback of the estimation error uses an observer structure that is similar to the one commonly used for state estimation. When an observer is used for fault diagnosis that satisfies the above properties associated with residual generation, it is called the Unknown Input Fault Detection Observer [1].

The above procedure only ensures that the occurrence of a fault is detected. Determining which fault (from the set of possible faults) has occurred is called fault isolation. Thus, to perform Fault Detection and Isolation (FDI), it is necessary that the faults leave distinct patterns in the residuals thereby making fault isolation possible. Generally, a strategy consisting of several different observers generating distinct residuals is employed. Each one of the observers is designed to be sensitive to a certain set of faults while remaining insensitive to other faults. Some processing of the residuals would be needed which would depend on the observer design and the number and modes of occurrence of the faults, i.e, whether multiple faults can occur simultaneously or not. Obviously, the FDI task is greatly simplified if perfect detection and isolation can be achieved by using one observer that generates a residual vector consisting of as many components as there are faults. Each component of the residual is affected only by a certain fault and unaffected by all other faults and unknown inputs. This problem of designing such an observer is called "Restricted Diagonal Detection Filter Problem".

Most systems, and especially those considered as model systems in chemical engineering literature are inherently nonlinear. Thus, there is a strong reason to explicitly consider design of nonlinear observers based on nonlinear models of the original process. Unlike estimation, observer design for fault diagnosis in nonlinear systems has received less attention. The general problem of solving for perfect decoupling of residuals in nonlinear systems is difficult. Hence, most of the reported work pertains to certain specific classes of nonlinear systems and can be distinguished in terms of the observer design and how the various components (states, inputs, outputs, faults, disturbances) contribute to the system nonlinearity. The observer design proposed in this paper is applicable for nonlinear systems in which the states, inputs and faults can affect the system dynamics in a nonlinear manner. This considerably extends the class of nonlinear systems for which disturbance decoupled residuals can be designed. Also, although the observer is nonlinear, it only uses a linear transformation of the states, thus avoiding the need to carry out a nonlinear transformation or solving a partial differential equation, as suggested in literature. [1,2,3].

The problem of designing a suitable unknown input observer for a certain class of nonlinear systems that satisfies the above conditions is the main focus of this work and this observer will be referred to as the “Nonlinear Diagonal Unknown Input Fault Diagnosis Observer”. The novel and main contributions of this paper are as follows: i) Two new, different nonlinear diagonal fault diagnosis observer designs are presented that are valid for a wider class of nonlinear systems than those considered in literature. The second observer incorporates a structured residual feedback which is conceptually tractable and implementable. ii) The diagonal structure of the observer greatly simplifies the design procedure and obviates the need for designing multiple observers to perform fault isolation. iii) Lyapunov analysis is used to prove convergence of the observers in the presence of multiple step faults. iv) The procedure is validated by simulations of multiple fault cases in standard test bed examples: the exothermic CSTR and counter-current heat exchanger.

References

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