Computers and Electrical Engineering 43 (2015) 17–32

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Hybrid computing techniques for fault detection and isolation, a review ☆

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ARTICLE INFO

Article history:
Received 23 July 2013
Received in revised form 24 December 2014
Accepted 29 December 2014
Available online 19 March 2015

Keywords:
Soft computing
Fuzzy logic
Fault detection
Fault isolation
Lab-scale tank system

ABSTRACT

The classical model-based methods had often proven to be unable to provide acceptable solutions to modern fault diagnosis systems. Therefore, model-free or soft computing techniques such as fuzzy logic, Artificial Neural Networks (ANNs) and Genetic Algorithms (GAs) had become more attractive in industrial applications of fault diagnosis. In this paper, three SC schemes are explored to solve the problem of detecting unprecedented changes and finding the failed state components. First, individual fuzzy systems, ANN and GA are implemented on a fault diagnosis scheme. Then, hybrids of these techniques are applied to enhance the fault diagnosis precision. This approach allows gaining critical information about fault presence or its absence in the shortest possible time. The proposed scheme was simulated and evaluated extensively on a benchmark laboratory scale coupled-two-tank system. The results are encouraging, showing especially, that hybrid GA + ANFIS (GANFIS), outperformed significantly the other techniques.

1. Introduction

Process faults, if undetected, have a serious impact on process economy, product quality, safety, productivity, and pollution level. In order to detect, diagnose and correct these abnormal process behaviors, efficient and advanced automated diagnostic systems are of great importance to modern industries. The main objective of Fault Detection and Isolation (FDI) is to provide early warnings to operators, so that appropriate actions can be taken to prevent the breakdown of the system after the occurrence of faults. Complete reliance on human operators to monitor the systems conditions is often difficult. For instance, in chemical processes several kinds of failures may compromise safety and productivity. In fact, the occurrence of faults may affect the efficiency of the process, for instance, lower product quality or, in the worst scenarios, could lead to fatal accidents (temperature run-away) with injuries to personnel, environmental pollution, and equipment damage. Major failures to be considered in chemical processes are: actuator failures (electric-power failures, pump failures, valves failures), process failures (abrupt variations of some process parameters, side reactions due to impurities in the raw materials) and sensor failures. To tackle these difficulties, FDI techniques were developed.

Model-based approach is popular for developing FDI techniques [1,2]. It mainly consists of two stages [3]. The first one is to generate residuals by computing the difference between the measured output and the estimated output obtained from the model of the system. Any departure from zero indicates a fault has occurred [4]. However, these methods are developed

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. Zhihong Man.

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http://dx.doi.org/10.1016/j.compeleceng.2014.12.015
0045-7906/

mainly for linear systems assuming that a precise mathematical model of the system is available. This assumption, however, may be difficult to satisfy in practice, especially as engineering systems in general are nonlinear and are becoming more complex [5,6].

To overcome these limitations, soft computing has emerged as a new paradigm for modeling and computing that parallels human abilities in learning and reasoning on problems involving strong complexity and uncertainty. In contrast with hard computing methods that only deal with precision, certainty, and rigor, it is effective in acquiring imprecise or sub-optimal, but economical and competitive solutions to real-world problems. As we know, *qualitative* information from practicing operators may play an important role in accurate and robust diagnosis of motor faults at early stages. Therefore, the introduction of soft computing to this area can provide us with the unique features of adaptation, involving embedded linguistic knowledge over conventional schemes [7–9]. Nevertheless, soft computing techniques had shown significant limitations as well. These include inherent specific limitation of each technique when applied apart. For instance, fuzzy logic has big capacity of uncertainty and vagueness handling, but it is very limited with respect to learning ability. Conversely artificial neural networks constitute an important model-free approach to learn complex systems behavior but again are very limited in tracking dynamic uncertainties that are present for many interesting systems and problems. Hybrid approaches are then introduced and thought to remedy at least partially to these limitations by integrating the capabilities of both in one system [10–14].

The contribution of this paper is twofold; First it provides with a thorough review on the application of soft-computing techniques, e.g., artificial neural networks, fuzzy-logic and genetic algorithms to FDI (Fault Detection and Isolation) with an extensive list of references. Then, with several experimental validation and results the effectiveness of these techniques is shown in fault detection and parameter estimation using a two-tank fluid control problem. It is also shown that the hybrid GA + ANFIS or (GANFIS) outperforms other techniques.

The structure of the paper is the following: Section 2 describes comprehensively the work done in fault diagnosis using expert systems, fuzzy logic and neural networks. Section 3 introduces the proposed scheme of soft computing application for the fault diagnosis problem. The proposed scheme for fault diagnosis with soft computing is presented in Section 4, which discusses the application of soft computing techniques including fuzzy logic, neural network, genetic algorithm, ANFIS and GANFIS on an two-tank FDI system. Section 5 gives the evaluation of the proposed scheme on a physical fluid level system and finally some conclusions are given in Section 6.

2. Related works

Soft computing techniques had been recently used to develop models for FDI problems [10–12]. These models not only can represent a wide class of nonlinear systems with arbitrary accuracy [13,14], they can also be trained from data. For these reasons, they have been used as models to generate residuals for fault detection [15]. However, it is very difficult to isolate faults, as these networks are black boxes in nature. Furthermore, it is also desirable that fault diagnostic system should be able to incorporate the experience of the operators [16]. Fuzzy reasoning allows symbolic generalization of numerical data by fuzzy rules with the direct integration of the experience of the operators in the decision making process of FDI in order to achieve more reliable fault diagnosis [17]. An up-to-date presentation of motor fault detection and diagnosis methods was recently published in [18,19].

The model-based methods are based on *a priori* knowledge and can be broadly classified as qualitative or quantitative. A sequential integration approach (Fig. 1) for fault diagnosis is proposed in this paper. The evaluation of both the Proposed

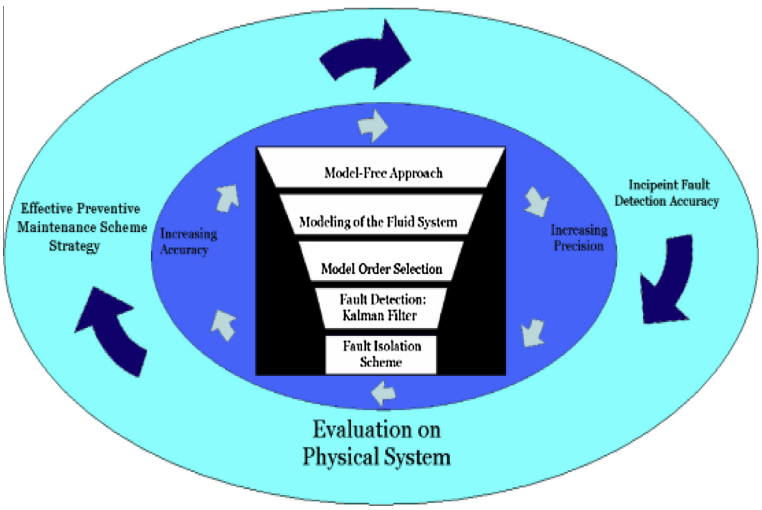

Fig. 1. A sequential integration approach for fault diagnosis (courtesy from [12]).