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Multi-Fault Diagnosis Based on Hybrid Bio-Inspired Algorithm ACO-GA

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ABSTRACT

The fault detection and isolation (FDI) procedure increases the assurance of quality, reliability, and safety of industrial systems. Several faults may appear simultaneously, and the purpose of multi-fault diagnosis is to identify and locate these multiple faults. This work is particularly interested in the diagnosis based on the structural analysis of the system; residuals can be generated and used as fault indicators by model-based fault detection techniques. The isolation is dependent on the structure of the fault signature matrix. A new fault signature that represents the superposition of the fault is produced by simultaneous fault effects, resulting in an additional column in an extended signature matrix. This remedy is rather combinatorial. This research focuses on two methods to isolate multiple faults: (1) A modified enumerative method; (2) A hybrid ant colony optimization algorithm-genetic algorithm (Hybrid ACO-GA) is adapted to the MFD problem which has the advantage of a better research as well as the hybridization with GA.

KEYWORDS

Analytical redundancy relations (ARRs), Fault Detection and Isolation (FDI), Fault Signature matrix, Hybrid Ant Colony Optimization-Genetic Algorithm, Multi-fault diagnosis, Structural analysis

INTRODUCTION

Safety critical systems, such as aircraft, automobiles, nuclear power plants, and space vehicles, are becoming significantly more complex and interconnected. The recent advances in wireless technology, remote communication, computational capabilities, sensor technology, and standardized hardware/software interfaces have further increased the complexity of these systems. This complexity may result in failures of multiple components. Hence, there is a need to develop smart on-board diagnostic algorithms that can determine the most likely set of failure causes in a system, given observed test outcomes over time (Ouyang et al., 2023). Fault detection and isolation (FDI) is an essential aspect of Industry 4.0, which refers to the integration of digital technologies in manufacturing processes. FDI in Industry 4.0 involves the use of advanced monitoring and data analytics techniques to detect and isolate faults or anomalies in industrial systems (Webert et al., 2022; Kang et al., 2022).

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In some systems, many defects may also manifest at once. This circumstance often arises when a first fault occurs, but the system has not been halted, either because the first fault was not serious or had a slow impact. In the meanwhile, a second problem arrives. When a reconfiguration approach is applied, this circumstance occurs more frequently. Reconfiguration techniques modify the control law, enabling production to go on even when a defect occurs.

The presence of two simultaneous faults in the system results in a new fault signature (Koscielny, 1993), which corresponds to the superposition of the two fault effects. According to the linearity hypothesis, processing the isolation of multiple faults using an expanded incidence matrix that includes a new column for each combination of faults may result in a combinatorial solution.

Multi-fault diagnosis (MFD) is a key issue in fault diagnosis technology because multiple faults commonly exist in engineering and complex systems. Zhang et al. (2015) did a survey on fault mechanism, manifestation of symptoms, and approach thinking for MFD. The MFD problem originates in several fields, such as medical diagnosis (Yu et al., 2007), error correcting codes, speech recognition, distributed computer systems, and networks (Odintsova et al., 2005). The MFD problem in largescale systems with unreliable tests was first considered by Shakeri et al. (1998).

The problem at the origin of this study is to study the possibility of the occurrence of several failures (or faults) simultaneously in a system, and that it is not interrupted or corrected after the first fault. The monitoring system in this case must diagnose the presence of different faults by making the best use of the structural properties of the system studied. MFD identifies multiple faults in a system, based on one or more symptoms and can be used as part of an overall diagnostic system or as a separate system. Its importance is evident in modern complex systems because they are systems characterized by the interconnection of several components, and the relationships describing the processes can be of different types (algebraic, differential). On the other hand, the complexity of this type of diagnosis plays an important role in the performance of an overall system.

Specifically, the objective of the research presented in this paper is to determine the possibilities of combining the effects of several defects on the system components. In addition, to study the situation in depth, two algorithms are presented and fully implemented to explore their possibilities and to evaluate the quality of their respective results. One is based on the standard approach that we have reduced, which consists in identifying and testing all possible combinations of faults, as well as the temporal and combinatorial inconsistencies that may occur. The other bio inspired algorithm ACO-GA uses different techniques of research and best exploration strategy to identify appropriate combinations of defects using simple elements.

This choice was guided by the fact that the reduced exact algorithm remains the reference in terms of complete, exhaustive, and exact solutions, and that the ACO-GA offers the best quality/performance ratio, especially when the system is large.

This paper is organized as follows: The first section introduces our research while the second section presents background about different methods for diagnosis and some definitions. Then the proposed approaches are presented in the third section. After that, in the fourth section we describe the steps of the ACO-GA algorithm. In the fifth section, we discuss the results obtained. Finally, a conclusion and references are given.

BACKGROUND

Early detection and isolation of faults are critical tasks in modern process industries. Many research works have been made during last decades to improve fault detection and isolation methods. Existing methods can be grouped into two general categories: model-based methods (Venkatasubramanian et al., 2003) and data-driven methods (Yin et al., 2014).