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Analysis and generalization of fault diagnosis methods for process monitoring

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ABSTRACT

In process monitoring, several diagnosis methods have been used for fault diagnosis. These methods have been developed from different backgrounds and considerations. In this paper, five existing diagnosis methods are analyzed and generalized. It is shown that they can be unified into three general methods, making the original diagnosis methods special cases of the general ones. Also, a new form of relative contributions is proposed. An analysis of the diagnosability shows that some diagnosis methods do not guarantee correct diagnosis even for simple sensor faults with large magnitudes. For faults with modest fault magnitudes, Monte Carlo simulation is applied to compare the performance of the diagnosis methods.

1. Introduction

Process monitoring is used in industry to detect and diagnose abnormal behavior of processes. Multivariate statistical methods and model-based methods are employed in process monitoring. Among the statistical methods, a popular method used in industry is principal component analysis (PCA) [11,18,19]. PCA partitions the measurement space into a principal component subspace (PCS) and a residual subspace (RS). Fault detection makes use of fault detection indices. A fault is detected when one of the fault detection indices is beyond its control limit. After a fault is detected, it is necessary to diagnose its cause. There exist several methods to perform fault diagnosis. Some of these methods examine contributions of a variable to a fault detection index with the idea that the contributing variables will have high values. Contribution analysis methods that have been proposed include complete decomposition contributions (CDC), partial decomposition contributions (PDC), diagonal contribution (DC), reconstruction-based contributions (RBC), and angle-based methods (ABC). Table 1 shows the diagnosis methods, the authors who proposed them and the indices they were used with. As can be seen, some diagnosis methods have not been proposed for all fault detection indices. In addition, Dunia et al. [6] propose to use a reconstructed index for fault diagnosis which is related to RBC. It is not clear, however, whether these diagnosis methods are independent, and which methods would outperform for a specific detection index.

An essential requirement for fault diagnosis is to avoid misdiagnosis as much as possible. Although contribution plots have been popularly used as fault diagnosis methods, no rigorous analysis of diagnosability is given until recently [1,2]. Contribution plots basically calculate the contributions of variables under a fault situation and pick variables with large contribution as the likely cause of the fault. With this notion, a well-defined contribution analysis should have the following desirable properties:

1. When no faults are present, all variable contributions should have statistically the same mean. This will establish a level ground to compare the contributions when there is a fault; and
2. if a fault is mainly attributed to one variable, the contribution of that variable should be the largest.

One objective of this paper is to reveal which fault diagnosis methods possess the above properties. In order to do the analysis of the diagnosis methods, they are expressed in general forms so that they can be used with any fault detection index [3]. Then, it is shown that the diagnosis methods can be unified into general diagnosis methods, and control limits for these methods are provided. Furthermore, a new form of relative contribution is proposed. An analysis of the diagnosability of the unified methods and their relative contributions is performed, and the results are compared for the different diagnosis methods. Monte Carlo simulation is applied to compare the performance of the diagnosis methods when single sensor faults with modest fault magnitudes happen in a system. Finally, conclusions are given.

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