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Matroid algorithm for monitorability analysis of bond graphs

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Abstract

The monitorability analysis (ability to detect and isolate faults) using a model is presented. A foundation of this structural property using bond-graph model is proposed. The present paper deals with independent residual generation based on binary matroid, especially chain groups over GF(2). The methodology is applied to bond-graph model, and from the structural point of view, for this task, a matroid intersection algorithm is used to compute the maximum matching.

Keywords: Bond graph; Matroid; Fault detection and isolation; Process engineering; Chain group matroid; Structural analysis

1. Introduction

In 1935, Whitney realized the mathematical importance of an abstraction of linear dependence. In 1960, Edmonds connected matroids with combinatorial optimization. Since then, several researches were published [1,2].

A matroid may be defined by a finite set E and a non-empty set of so-called independent subsets or dually, the dependent subsets. With matroids, one may formulate rather compactly and solve a large number of combinatorial problems: bases, circuits, rank function and so on [3]. They afford an uncluttered view of essential problem features. If the

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field is the binary field i.e., GF(2), any undirected graph may be represented by a certain binary matrix, the latter can be generalized by a binary matroid. Many kinds of matroids can be found in literature, only regular matroids may be determined by an oriented graph. A bond graph provides a picture from which separate integral representation of the structure matroid [4] and its dual may be obtained. Using matroid theory, Birkett has proved that bond graph may be regarded as a more complete pictorial device than the graph [5]. The linear programming problem and the complementarity one are abstracted on oriented matroids [6] and algorithms for those problems rely on the properties of circuit families.

The problem of fault detection (FD) is to check for the presence of crash. When no fault is present in the system, it is in the safe mode, otherwise it is in the faulty mode. In the first case, the analytical residual redundancy relations (ARRs) vanish, in the second case, they are different from zero if some fault arises, and we have to decide among a number of faulty modes, which mode is incriminated, this is the isolation process (FI). In the FDI literature, faults are modelled as additional terms in a state space model. Several methods of ARR generation have been developed, the method based on bond-graph model is considered [7]. Using this model, complex and large scale systems are modelled in a unified way from the point of energy flowing view [8]. Furthermore, bond graph, thanks to causality concept, is a suitable tool for fault diagnosis [9], and faults have physical signification, they may be those of actuators, sensors or system components.

The main contribution of this paper is introducing two kinds of chains: the multiport bond graph by means of integral chain groups, and residual chains to cope with FDI structural analysis through bond-graph methodology. This paper is organized as follows: in the second section some mathematical background are recalled. In Section 3, the bond-graph matroid is introduced based on the integral generating chain group. Section 4 deals with analytical redundancy using bond-graph model, whereas a simple example is presented in the last section.

2. Mathematical background

2.1. Definitions

Definition 1. Let R be a commutative ring with unit element and no divisors of 0. R may be the fields of residus modulo 2. A chain on E over $\mathfrak{R}$ is an application $f : E \to \mathfrak{R}$.

Definition 2. $\sup p(f) = \{a \in E \text{ s.t } f(a) \neq 0\}$ is the support of 'f'.

Definition 3. Chain group N of chains on E over $\mathfrak{R}$ is a group, i.e., $f + g\ (a) = f(a) + g(a)$ and $\lambda \in \mathfrak{R}\ \lambda(f)\ (a) = \lambda\ .f(a)$.

Definition 4. f is said to be an elementary chain iff $f \neq 0$ and there is no zero chain g such that $\text{supp}(g) \subset \sup p(f)$.

Definition 5. The class of supports of elementary chains in N is the class of circuits of a matroid $M(N)$ on E.

Definition 6. A binary chain group over $\mathfrak{R}$ is the fields of residus modulo 2 i.e., $N = \{f : E \to \{0, 1\}\}$.