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A robust deadlock prevention control for automated manufacturing systems with unreliable resources

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ABSTRACT

For a deadlock problem in automated manufacturing systems (AMSs) with unreliable resources, the existing control methods mostly belong to the class of deadlock avoidance. This paper focuses on deadlock prevention for AMSs with an unreliable resource. We use Petri nets to model such AMSs and develop their robust deadlock prevention controller. The controller is designed in three layers. In the first layer, the optimal controller is used to ensure that the system can process all types of parts in the absence of resource failures. The function of the second layer controller is to ensure that, when a fault of the unreliable resource occurs at any reachable state, all parts not requiring the faulty resource can be processed and all resources, that they need, but are held by parts requiring the faulty resource for further processing, can be released in order to maximize the resource utilization. The so-called second-level deadlocks caused by the controllers are prevented by the third layer controller. These three controllers together are shown to satisfy the desired properties and hence, able to ensure the robust deadlock-free operation of AMSs with an unreliable resource.

1. Introduction

An automated manufacturing system (AMS) is a computer-controlled production facility exhibiting a high degree of resource sharing. It consists of a set of workstations and can process different types of parts based on their prescribed sequences of operations. In such a system, the interacting parts and shared resources can lead to deadlock states under which the entire system or a part of it remains indefinitely blocked and cannot terminate its tasks. Thus, to effectively operate an AMS and meet its production objective, and make the best use of resources in the system, it is necessary to properly allocate shared resources to various processes such that deadlock never occurs.

Researchers have made tremendous progress in deadlock analysis and developing deadlock control policies for a variety of AMSs with and without routing flexibility [2,6,9–11,13,15–19,21,24,26,30,31,35,36] and those with and without unreliable resources [3,4,14,20,29,32,37].

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The existing control policies for the deadlock problem of AMSs with reliable resources fall into two classes, i.e., deadlock prevention and deadlock avoidance. The former establishes in advance offline control or resource allocation policies such that the resulting operations are deadlock-free [5,7,9,10,15,16,18,22,24,26,31,35,36]; while the latter is an online control policy that uses feedback information on the current state or resource allocation status and future resource requirements, to keep the system away from deadlocks [2,11,12,19,30,33,35,36].

Many researchers use Petri nets as a formalism to describe AMSs with reliable resources and develop deadlock resolution methods [1,8,10,15,16,18,23–27,31,34–36,38]. Most Petri net-based methods for preventing deadlock are to add some control places and related arcs to strict minimal siphons such that no siphon can be emptied [10,15,16,18,24,26,31], or to maximal perfect resource-transition circuits such that none of them can be saturated [35,36]. While Petri net-based deadlock avoidance policies determine whether or not a part can start its next operation by using a one-step look-ahead method [36]. In contrast, few researchers have addressed the control implications of resource failure. In a real world, resource failures can occur. They reduce efficiency and resource utilization, which may lead to deadlocks and degrade the performance of AMSs greatly. Thus, it is essential to develop robust control policies to handle them. For AMSs with unreliable resources, the existing deadlock control strategies mostly fall into the class of deadlock avoidance. They are based on the discrete event system models and most of them are based on the Banker's algorithm and neighborhood constraints [3,4,20,32,37]. Park and Lim derive the necessary and sufficient conditions for a fault-tolerant robust supervisor and apply them to a practical work cell [29]. Lawley and Sulistyono develop a robust deadlock avoidance policy and neighborhood constraints for manufacturing systems with unreliable resources [20]. The buffer spaces are allocated such that when an unreliable resource fails, the system can continue to produce all type of parts requiring no failed resource. Chew et al. [3] develop two supervisors to guarantee the robust operation of AMS with multiple product routes and unreliable resources. They relax the restriction that each part type requires at most one unreliable resource in its route by using a central buffer. Hsieh presents a suboptimal polynomial-complexity deadlock avoidance algorithm that can operate in the presence of unreliable resources for assembly processes based on controlled assembly Petri nets [14]. In [17], Liu et al. propose a supervisor for a class of Petri nets called systems of simple sequential processes with resources based on divide-and-conquer strategy. Yue et al. propose a deadlock avoidance policy for AMS with unreliable resources by using the improved Banker's Algorithm and a set of remaining resource capacity constraints [37].

As mentioned above, we find little manufacturing research literature on robust supervision. We hardly find any work on deadlock prevention for AMS with unreliable resources. This work deals with the deadlock control problem in AMSs with an unreliable resource and develops their deadlock prevention controllers. Our control objective is to guarantee that the controlled system is live in absence of resource failure, and parts not requiring the unreliable resource can be processed sequentially when an unreliable one fails.

This work differs from the existing avoidance work on deadlock problems in AMSs with unreliable resources. We use Petri nets to model them and develop their robust controller for deadlock prevention. Our controller has a total of three layers. Our first control objective is to guarantee that the system is live regardless a resource fails or not. To this end, the first layer controller is designed to control the whole system. When the unreliable resource fails, all parts in the system requiring the failed resource for their future processing are unable to be completed until it is repaired. The Petri net model is divided into two subnets according to whether or not the completion of the parts in them requires the unreliable resource. The first subnet, in which any part requires the unreliable resource, is called as a blocked subnet (BN); while another subnet, called as a free subnet (FN). A part in BN cannot be finished or is blocked by the failed unreliable resource. Note that, when the unreliable resource fails, parts in BN may occupy some resources required by the parts in FN, i.e., those not requiring the failed resource, thereby forming another blockage. To ensure that all parts not requiring the unreliable resource can be completed and in order to maximize the use of resources, all resources required by the parts in FN should be released. Our second objective is thus to control the system such that the failed unreliable resource does not block the processing of parts that do not require it. For this objective, the second layer controller is designed. Since the applied controllers can cause the so-called second-level deadlock, the third layer controller is designed. They are combined to achieve the desired properties and ensure robust deadlock-free operations of AMSs.

The rest of this paper is organized as follows. Some preliminaries of Petri nets used throughout this paper are briefly reviewed and Petri net models for AMSs with unreliable resources are firstly established in Section 2. In Section 3, specifications of robust controllers for AMS with unreliable resources are presented. A novel robust Petri net controller for AMS with an unreliable resource and its three layer controllers are developed in Section 4. An example is given to validate the proposed method in Section 5. The conclusions are drawn in Section 6.

2. Petri net modeling of AMSs with unreliable resources

In this section, we develop the Petri net model of AMS with unreliable resources. Let us first briefly review the basic concepts and notations of Petri nets. For more details, a reader is referred to [28].

2.1. Basic definitions

A Petri net is a 3-tuple $N = (P, T, F)$, where P and T are the sets of places and transitions, respectively. $F \subseteq (P \times T) \cup (T \times P)$ is the set of directed arcs.